International Energy Agency

Programme of Research, Development and Demonstration on District Heating

IEA District Heating

GUIDELINES FOR CONVERTING BUILDING HEATING SYSTEMS FOR HOT WATER DISTRICT HEATING

Published by

Novem

Netherlands agency for energy and the environment

acting as operating agent for the IEA District Heating Project

92-00201/

GUIDELINES FOR CONVERTING BUILDING HEATING SYSTEMS FOR HOT WATER DISTRICT HEATING

CONTRACT SERIAL NO. 23440-8-9072-01-SQ

CONTRACT REQ' NO. 23440-8-9072

CONTRACTOR: PEI ENERGY CORP.

Alexander H. Sleiman
Mark Spurr *
Anders Rydaker **
Michael Karnitz ***

---

* Resource Efficiency, Inc.
** FVB District Heating Enginerring
*** Oak Ridge National Laboratory

January 1990

Prepared by
District Energy St. Paul, Inc.
St. Paul, Minnesota, U.S.A.

MICROMEDIA

under contract to

132 pp

Prince Edward Island Energy Corp.
Prince Edward Island, Canada

GUILDELINES FOR CONVERTING BUILDING

HEATING SYSTEMS FOR HOT WATER DISTRICT HEATING

Contractor: P.E.I. Energy Corporation
Charlottetown, P.E.I.
Canada

Sub Contractor: District Energy St. Paul, Inc.
St. Paul, Minnesota

Authors: Alex Sleiman
Mark Spurr, Resource Efficiency Inc.
Anders Rydaker, FVB District Heating Engineering
Michael Karnitz, Oak Ridge National Laboratory

Keywords: District Heating, Heat Exchangers, Hot Water Heating, Building Heating, Energy Conservation, Heating Systems, Air Handling Systems, Piping System.

ERRATA

Suggested minimum fouling factors, presented on page 54, Section 3.5.2, first paragraph, and page 106, Section 5.2, third paragraph, should be adjusted as follows:

For space heating, at least 0.0003 square foot per °F per Btu per hour (about 0.00006 square meter per °C per Watt).

For domestic hot water, at least 0.0004 square foot per °F per Btu per hour (about 0.00008 square meter per °C per Watt).

TABLE OF CONTENTS

PREFACE 7

ABSTRACT 9

ACKNOWLEDGEMENTS 10

LIST OF FIGURES 11

LIST OF TABLES 12

ABBREVIATIONS 13

UNITS AND CONVERSION FACTORS 13

1. INTRODUCTION
   - 1.1 Purpose 16
   - 1.2 Using the Guidelines 16

2. FUNDAMENTALS OF MEDIUM TEMPERATURE DISTRICT HEATING
   - 2.1 How District Heating Works 20
     - 2.1.1 Heat source 20
     - 2.1.2 Distribution 20
     - 2.1.3 Customer installation 24
   - 2.2 Design Philosophy 24
     - 2.2.1 General considerations 24
     - 2.2.2 Heat source 26
     - 2.2.3 Distribution 26
     - 2.2.4 Customer installation 26
   - 2.3 Benefits of Hot Water District Heating 29
     - 2.3.1 Benefits to the community 29
     - 2.3.2 Benefits to the user 29
       - a. Reliability 29
       - b. Tenant comfort 29
       - c. Reduced investment 29
       - d. Building operation costs 30
       - e. Esthetics and environment 30
       - f. Energy efficiency 30
       - g. Fuel flexibility 30

3. DESIGNING FOR INTERFACE WITH DISTRICT HEATING
   - 3.1 Introduction 34
   - 3.2 Building Heat Exchanger Station 34
     - 3.2.1 Heat exchangers 34
     - 3.2.2 Temperature controls 37
     - 3.2.3 Heat Meters 38
       - a. Meter types 38
       - b. Designing for meter installation and maintenance 38
     - 3.2.4 Other equipment 41
     - 3.2.5 Location of heat exchanger station 42

3.3 Direct Connection 42
3.4 Secondary Systems 45
3.4.1 General considerations 45
3.4.2 Distribution pumps 50
3.4.3 Heating and ventilation equipment 50
a. General considerations 50
b. Air handling systems 51
3.4.4 Water treatment 53
3.4.5 Expansion system 53
3.5 Domestic Hot Water 53
3.5.1 General considerations 53
3.5.2 Domestic hot water heat exchangers 54
3.5.3 Temperature control 56
3.5.4 Storage 56
3.6 Radiant Floor Heat and Snow Melting Systems 56

4. BUILDING CONVERSION
4.1 Introduction 62
4.2 Procedure for Building Conversion 64
4.2.1 Survey and schematic design 65
4.2.2 Building heating load 65
4.2.3 Component compatibility 66
4.2.4 Conversion concept and costs 66
4.2.5 System optimization and detailed design 66
4.2.6 Construction schedule 67
4.2.7 Testing and commissioning 67
4.3 Steam Systems 67
4.3.1 Steam distribution 67
a. General considerations 67
b. One-pipe systems 68
c. Two-pipe systems 68
d. Pipe insulation 68
e. Hard-to-heat areas 71
4.3.2 Heat exchangers 71
4.3.3 Radiation 71
a. Radiators and convectors 71
b. Fin-tube and baseboard convectors 76
4.3.4 Air handling systems 76
a. Heating coils in air handling units 76
b. Reheat and booster coils in duct systems 83
c. Fan-coil units 83
d. Unit heaters 83
e. Cooling coils used for heating in winter 86
4.4 Hot Water Systems 87
4.4.1 Hot water distribution 87
4.4.2 Radiation 88
4.4.3 Air handling systems 88
4.4.4 Unitary heat pumps 88
4.5 Gas/Oil-Fired Systems 89

4.5.1 Warm air furnaces 89
a. Furnace retrofit 89
b. Furnace replacement 92
c. Coil selection 92
d. Coil construction 92
e. Coil testing 93
f. Coil mounting and transitions 93
g. Temperature controls and trim 93
4.5.2 Rooftop units 94
4.5.3 Radiant heaters and unit heaters 94
4.6 Electric Systems 97
4.6.1 Electric resistance furnaces 97
4.6.2 Rooftop units and air handling units 97
4.6.3 Air-to-air heat pumps 97
4.6.4 Other systems 97
4.7 Control Systems 97
4.7.1 Requirements for conversion 97
4.7.2 Upgrading controls for energy efficiency 97
a. Outside air damper 98
b. Control valves 98
c. Temperature sensors 98
d. Controllers 98
e. Room Thermostat 98
f. Day-Night Thermostat 99
4.8 Heat-Driven Cooling Systems 99
4.9 Humidification and Kitchen Steam Systems 99
4.10 Energy Conservation 100
4.10.1 Overview 100
4.10.2 Ventilation 100
4.10.3 Building management systems 101
4.11 Other Considerations 101
4.11.1 Heating mechanical rooms 101
4.11.2 Asbestos 101
4.11.3 Recapture of space 101
4.11.4 Staffing and management 102

5. SUMMARY OF PERFORMANCE SPECIFICATIONS FOR CRITICAL COMPONENTS
5.1 Introduction 106
5.2 Heat Exchangers 106
5.3 Strainers 107
5.4 Shut-off Valves 107
5.5 Control Systems 107
5.6 Piping 108
5.7 Insulation 108
5.8 Pressure Gauges and Thermometers 108
5.9 Balancing Valves 108
5.10 Unions 108
5.11 Safety Valves 108
5.12 Materials Used in Hydronic Piping and Equipment 109

APPENDIX - CASE HISTORIES
1. Ramsey County Courthouse/St. Paul City Hall ..... A- 3
2. Hotel Jamestown ..... A- 7
3. Gillette Industrial Facility ..... A- 9
4. Garfield School A-13
5. Charlottetown Hotel A-16

GLOSSARY A-20

PREFACE

The IEA was established in 1974 within the framework of the OECD to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty-one IEA Participating countries to increase energy security through energy conservation, development of alternative energy sources and energy research, development and demonstration (RD&D). This is achieved in part through a programme of collaborative RD&D consisting of forty-two Implementing Agreements, containing a total of over eighty separate energy RD&D projects. This publication forms one element of this programme.

District Heating is seen by the IEA as a means by which countries may reduce their dependence on oil and improve their energy efficiency. It involves the increased use of indigenous or abundant fuels, the utilization of waste energy and combined heat and power production.

A number of ten IEA countries decided to collaborate in an assessment and demonstration programme. The Implementing Agreement: 'Programme of Research, Development and Demonstration on District Heating' was established at the end of 1983 and signed by Belgium, Canada, Denmark, Federal Republic of Germany, Finland, Italy, Netherlands, Norway, Sweden and U.S.A.

The following technical areas have been assessed:

- Development of heat meters
- Cost efficient distribution and connection systems for areas of low heating density
- Small size coal-fired hot water boiler
- Medium size combined heat and power plants
- Low temperature applications in district heating systems

The results of these topics have been presented in printed reports.

Furthermore, it was agreed by the participants to continously monitor ongoing research, development and demonstration projects in Participating Countries and to deliver summary reports on topics of special relevance.

In 1987 it was decided by nine of the original ten participating countries to continue the planning and implementation of co-operative projects under an Annex II.

The Netherlands Agency for Energy and the Environment, is the Operating Agent for this Annex II, in which the following technical areas have been assessed:

1. Consumer installations
2. Piping
3. Advanced fluids
4. Heat meters
5. Advanced heat production technology
6. User friendly turbine selection

This report is the combination of two draft reports to the International Energy Agency, both dealing with the subject of converting buildings to use hot water district heating.

Under Annex 1 of the IEA District Heating Project, a draft report was prepared by Michael Barnes and Michael Karnitz of Oak Ridge National Laboratory as a United States project concentrating on conversions for buildings under 30,000 Btu per hour (100 kW) peak load. Under Annex 2 a report was commissioned on the conversion of larger buildings using the Prince Edward Island Energy Corporation as a contractor.

In the final stages of preparing the report on the conversion of larger buildings the Experts Group reviewing the project decided to incorporate the earlier report so that one reference document would be available to the engineering community. It is hoped that the efforts of the many individuals that produced this document will prove to be useful in the implementation of district heating outside those countries that already have extensive experience.

R. J. Brandon
P.E.I. Energy Corporation

ABSTRACT

Guidelines are presented to assist engineers and contractors in designing and implementing conversions of buildings to medium temperature hot water district heating, i.e., distribution of water with a maximum temperature under 250°F (121°C) and a maximum pressure under 250 psig (1.7 MPa).

The guidelines are applicable to a variety of building types, including office, retail, residential, institutional and industrial. The guidelines address a wide variety of building sizes, from single-family residential to very large buildings. Portions of the report primarily directed toward small buildings are identified in Chapter 1.

Interface of new and retrofit building systems with medium temperature hot water district heating is discussed, including heat exchangers, heat meters, secondary distribution system, space heating terminal equipment, domestic hot water heating, and radiant floor heat and snow melting systems.

Specific guidelines for conversion of existing systems are provided, and are organized by type of heating medium or system (steam, hot water, gas/oil-fired or electric). For each heating medium, advice on conversion of specific types of distribution, radiation and air handling equipment is presented. Suggested performance specifications for key components are also summarized. Five case histories describe actual conversions which incorporate both traditional practices and creative solutions.

ACKNOWLEDGEMENTS

The authors wish to acknowledge and express appreciation for the contributions of many individuals to the development of these guidelines, including:

- Rob Brandon, Prince Edward Island Energy Corporation, for contributing many insights and comments during review of drafts, for providing the case study of the Charlottetown Hotel, and for capably guiding this project.

- Michael Wiggin, Energy, Mines and Resources Canada, who has once again been instrumental in bringing people and resources together to accomplish an important project.

- Hans Nyman, District Energy St. Paul, Inc., for his guidance and assistance throughout this project.

- Michael Barnes and L.V. Alwin of Scantec, Inc., for their role in developing the material oriented toward small building systems.

- Dr. Ishai Oliker, Joseph Technology Corp., for contributing the case history on the Jamestown Hotel and for serving on the Review Committee.

- Bart Murphy, Willmar Public Utilities, for contributing the case history on Garfield School.

- The members of the IEA Experts Committee and others who served on the Review Committee for this project, for their considerable expertise and many thoughtful comments: Ake Narfgren and Dr. Svend Frederiksen, Lund University Sweden; Ilkka Pirvola, Helsinki Energy Board, Finland; Peter Randlov, B. Hojlund Rasmussen, Denmark; Ian Kelly, Scouten, Mitchell, Sigurdson and Associates, Canada; Rudolf Jetzelsperger, R & I Enterprises, Canada; Michael Hartop, Public Works Canada; John Wright, Department of National Defence, Canada; Robert Tamblyn, Engineering Interface Ltd., Canada; Arno Sijben, NOVEM BV, Nederlands; Jaan Langseth, SINTEF, Norway; Dr. Christoph Dietsche, Stadtwerke Mannheim AG, Germany.

- LeRoy Gilliam, Graphics Illustrator at Oak Ridge National Laboratory, for preparing the schematics and other illustrations in this report.

LIST OF FIGURES

2.1 Elements of a District Heating System
2.2 Distribution System Pressure Differentials
2.3 Temperature of Primary Water in a District Heating System With a -20°F (-29°C) Design Temperature
2.4 Basic Building Heating System Schematic
2.5 Example of a Relationship Between Electricity Production, Heat Production and Hot Water or Steam Temperature
2.6 Pipe Diameter in Relation to Temperature Difference
3.1 Principal Connection Methods For Uniform Flow
3.2 Heat Exchanger Station
3.3 Typical Installation For Heat Meter
3.4 Direct Connection of Building System to District Hot Water
3.5 Direct Connection With Recirculation
3.6 Heating System With Several Sub-circuits and Distribution Pumps
3.7 Heating System With Multiple Sub-circuits Having Different Temperature Demands
3.8 Typical Sub-circuit Pumping System
3.9 Typical Indoor-Outdoor Controller Curve For Space Heating Equipment
3.10 Pump Characteristics at 50% Flow Rate
3.11 Typical Air Handling Unit With Freeze Protection
3.12 Domestic Hot Water Heater With Pre-Heater Section
3.13 Single Wall Heat Exchangers With Sweet Water Loop
3.14 Snow Melting and Underfloor Heating Systems
4.1 Basic One-Pipe Steam Heating System
4.2 One-Pipe Steam Heating System Modified For Hot Water District Heating
4.3 Typical Two-Pipe Steam Heating System (Gravity Return)
4.4 Typical Two-Pipe Steam Heating System (Gravity Return) With Boiler Pump and Receiver Set (High-Pressure System)
4.5 Two-Pipe Steam System Modified For Hot Water District Heating
4.6 Two-Pipe Steam System (High-Pressure) Modified For Hot Water District Heating
4.7a Typical Conversion of One-Pipe Steam Radiator
4.7b Typical Conversion of Two-Pipe Steam Radiator, Convector or Fin-Tube Element
4.8 Typical Air Heater Conversion
4.9 Typical Air Heater Water Connection with Circulating Pump For Freeze Protection
4.10 Recommended Coil Control Design
4.11 Alternative Coil Control Designs
4.12 Conversion of Horizontal Unit Heater
4.13 Conversion of Cabinet Unit Heater
4.14 Typical Warm Air Furnace (Gas, Oil or Electric) With Direct Expansion Cooling With Remote Refrigeration Condensing Unit Outside
4.15 Warm Air Furnace Converted to Hot Water Heating Using Hot Water Heating Coil Installed in Air Plenum
4.16 Typical Rooftop Unit
4.17 Typical Rooftop Unit Converted for Hot Water District Heating

LIST OF TABLES

3.1 Common Design Temperature Objectives For Heat Exchangers
4.1 Heating System Types
4.2 Conversion Suitability of Heating System Types
A.1 Summary of Case Histories
A.2 Courthouse/City Hall Conversion Cost Estimate
A.3 Gillette Facility Conversion Cost Estimate
A.4 Garfield School Conversion Costs
A.5 Charlottetown Hotel Conversion Costs

ABBREVIATIONS

Term	*Abbreviation*
British thermal unit	Btu
million British thermal units	MBtu
cubic feet	cu ft
foot or feet	ft
gallon or gallons (U.S.)	gal
hour	hr
kilowatt	kW
kilowatt hour	kWh
megawatt	MW
megawatt hour	MWh
pound or pounds	lb or lbs
pounds per square inch	psig
square	sq
degrees Farenheit	°F
degrees Celsius	°C
mega pascals	MPa
kilo pascals	kPa
domestic hot water	DHW
parts per million	ppm
shell and tube	S&T

UNITS AND CONVERSION FACTORS

In this report quantities are expressed first in English units, with the corresponding number using commonly used metric units shown in parentheses. Prefixes for English and metric units used in this report are k=1,000 and M=1,000,000.

To convert from	*To*	*Multiply by*
MBtu/hr	kW	293.1
MBtu	MWh	0.2931
inches	cm	2.54
inches	mm	25.4
psig	kPa	6.895
psig	MPa	0.0069
gallon (U.S.)	liter	3.7853
ft	m	0.3048
sq ft	sq m	0.0929
°F	°C	°C = (°F-32)/1.8
MPa	Bar	10

1. INTRODUCTION

1.1 Purpose

These guidelines are intended to assist engineers and contractors in designing and implementing conversions of buildings to medium temperature hot water district heating, i.e., distribution of water with a maximum temperature under 250°F (121°C) and a maximum pressure under 250 psig (1.7 MPa). The guidelines are applicable to a variety of building types, including office, retail, residential, institutional and industrial.

These guidelines are oriented toward the types of conditions most likely found in North American hot water district heating systems, i.e., service to a downtown core composed of a variety of building sizes and types, many of which are older buildings which must be converted from steam to hot water. This report focuses on indirect connection between the district hot water and building systems because this approach is more appropriate to these conditions. Direct connection is addressed in Section 3.3.

The purpose of these guidelines is to provide practical advice on converting buildings in the most cost-effective manner while ensuring that the system provides reliable and efficient heating using district hot water. This report is based on extensive experience in converting building systems and operating these systems with district hot water.

It is assumed that the user of these guidelines is an experienced heating, ventilation and air conditioning engineer or contractor, and therefore this report does not address general aspects of building system design and installation.

Due to the many variations in building codes among the various jurisdictions in the U.S. and Canada, these guidelines do not address specific requirements of codes, except to note, where appropriate, the importance of checking local code requirements.

These guidelines are not intended to supersede guidelines or regulations set by a specific district heating utility. In any building conversion project, the engineer should always consult the district heating utility regarding their specific requirements.

1.2 Using the Guidelines

A detailed Table of Contents is provided to facilitate use of these guidelines as a reference.

Chapter 2 provides an overview of the fundamentals of medium temperature hot water district heating, focusing on those elements of particular significance in designing a building heating system to use district hot water. Chapter 2 also briefly summarizes the benefits of hot water district heating.

Chapter 3 describes key points in designing building systems for interface with medium temperature hot water district heating. The chapter is relevant both for a building conversion and for design of a new building heating system. It addresses the interface between the building system and the district heating distribution system, and discusses building system design elements that are of relevance regardless of the type of building heating system that was originally in use. Topics include heat exchangers, heat meters, secondary distribution system, space heating terminal equipment, domestic hot water heating, and radiant floor heat and snow melting systems.

Chapter 4 discusses how to approach the conversion design for various types of building heating systems and components. The chapter begins with an overview of building system types and their relative ease of conversion. Following this introduction, a procedure for the conversion design process is suggested. Specific guidelines for conversion are then presented, and are organized by type of heating medium or system (steam, hot water, gas/oil-fired or electric).

For each heating medium, advice on conversion of specific types of distribution, radiation and air handling system equipment is presented. Ways to incorporate other energy conservation measures into the conversion design are also described. Last, a variety of miscellaneous considerations are addressed.

Chapter 5 summarizes suggested performance specifications for key components.

The Appendix presents five case histories, illustrating some of the topics covered in the guidelines through description of experience in actual building conversions.

The report concludes with a glossary.

2. FUNDAMENTALS OF MEDIUM TEMPERATURE DISTRICT HEATING

2.1 How District Heating Works

District heating is a system in which hot water or steam is distributed in pipes from a central heating plant to buildings for space heating, domestic hot water heating, space cooling and/or process heating. A district heating system contains three major elements: the heat source; a distribution system; and customer installations. These elements are depicted in Figure 2.1.

Hot water district heating systems can be subdivided into three groups based on peak temperature:

- Low temperature — under 190°F (88°C)
- Medium temperature — 190 to 250°F (88 to 121°C)
- High temperature — over 250°F (121°C)

This report is oriented toward medium temperature hot water systems, which generally have a maximum pressure under 250 psig (1.7 MPa).

2.1.1 Heat Source

Hot water is generated at the district heating plant using a conventional boiler, cogeneration system, waste heat boiler or other sources of energy. Heat sources are discussed in more detail in Section 2.2.2.

2.1.2 Distribution

District hot water is distributed from the heat source through supply pipes to the customers and is returned after heat has been extracted. Distribution is accomplished by pumps, which create a pressure differential between the supply and return lines.

Figure 2.2 illustrates the pressures in a simplified distribution system, using variable speed pumps, during winter (Figure 2.2-a) and summer (Figure 2.2-b). The pump head (PH) is selected to overcome the flow resistance in the supply and return lines plus the pressure differential in the customer installation at the end of the system (PC). The amount of water that flows through each building is governed by a control valve which is sensitive to the demand for heat in the building.

Modern hot water district heating systems supply hot water at a temperature which varies according to the outside temperature. By reducing the water temperature when the heating demand decreases, energy losses from the pipe system are reduced, and energy efficiency using low-grade heat sources can be increased, as discussed in Section 2.2.2. Heat losses in modern medium temperature hot water distribution systems are about 5-10% annually.

Variation of temperatures in district heating systems generally follows a curve such as the one shown in Figure 2.3. This example reflects a design temperature of -20°F (-29°C), which is appropriate for the state of Minnesota, U.S.A. Climatic conditions in other areas may be more or less severe, and would result in a different curve.

A common supply temperature range is 170°F (77°C) to 250°F (121°C). The low end of the range is in many cases the temperature required to meet domestic hot water needs

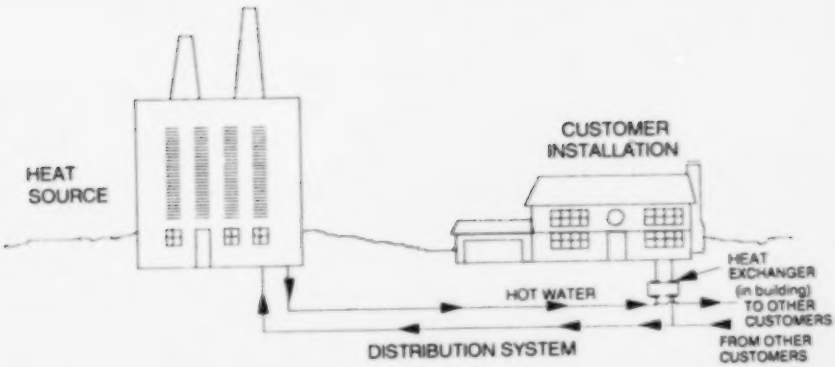
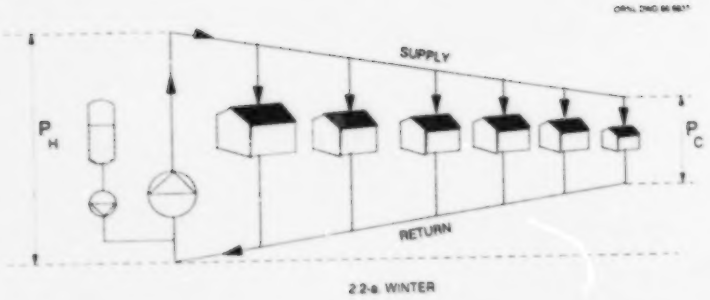


Figure 2.1: Elements of a District Heating System



P_H = Pump Head

P_C = Minimum Allowable Pressure Differential

Figure 2.2: Distribution System Pressure Differentials

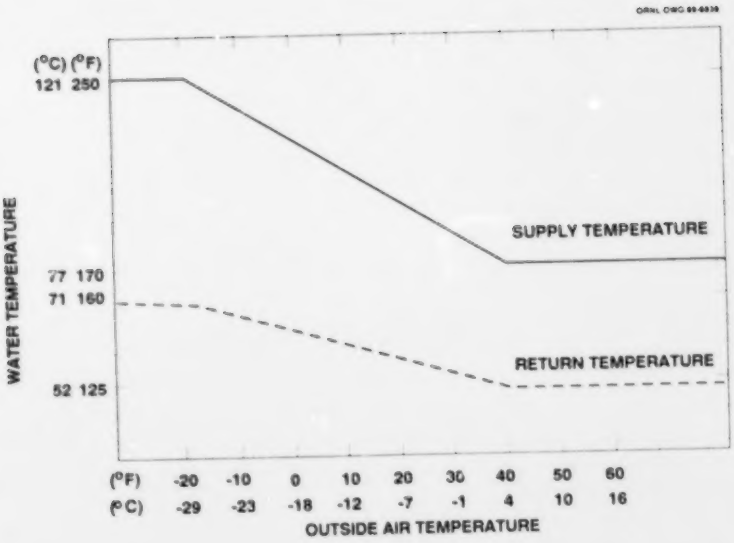


Figure 2.3: Temperature of Primary Water in a District Heating System with a -20°F (-29°C) Design Temperature

during the summer. However, if there are process heating loads or other higher temperature loads, summer temperatures may be higher.

2.1.3 Customer Installation

Building systems may be connected directly or indirectly to the district heating distribution system. With direct connection, the district heating water is distributed within the building to directly provide heat to terminal equipment such as radiators, unit heaters, etc. Guidelines for direct connection are addressed in Section 3.3.

This report focuses on designing building systems for indirect connection, in which a heat exchanger in the building transfers energy from the district heating distribution system (primary system) to the building distribution system (secondary system).

The building heat exchanger station is divided into primary and secondary sides, which are separated by one or more heat exchangers. The primary side of the heat exchanger is connected directly to the district heating distribution system. Figure 2.4 shows an example of a basic building system schematic including heat exchangers and secondary systems.

Extraction of energy in the heat exchanger is governed by a control valve which is sensitive to the building heat demand. The control valve should be designed to work within a specific pressure differential range, which varies significantly with distance from the plant as well as with the system load.

2.2 Design Philosophy

2.2.1 General Considerations

All elements of a district heating system should be designed to optimize the economics of the total system. To accomplish this, the heat source, distribution system and customer installations must be integrated so that total costs are minimized, and the design of all elements must be consistent with the temperatures, pressures and other parameters of the optimized system.

For example, the costs and benefits of lower temperatures in the primary system must be weighed. Benefits include potential utilization of low-grade, low-cost heat sources and low-cost piping materials and designs. However, these savings must be balanced against higher distribution costs due to a lower primary temperature differential and therefore larger pipe sizes and/or higher pumping costs.

Another example is the trade-off between distribution system costs and building conversion costs. It is generally most cost-effective to maintain a high temperature differential between supply and return lines, because this allows for smaller pipe sizes in the primary distribution system. These savings must be weighed against higher building conversion costs which may result from a requirement for a low primary return temperature.

In district heating systems serving mainly space heating and domestic hot water loads, the optimum design using currently available technology usually includes a peak supply temperature lower than 250°F (121°C) and a pressure lower than 250 psig (1.7 MPa).

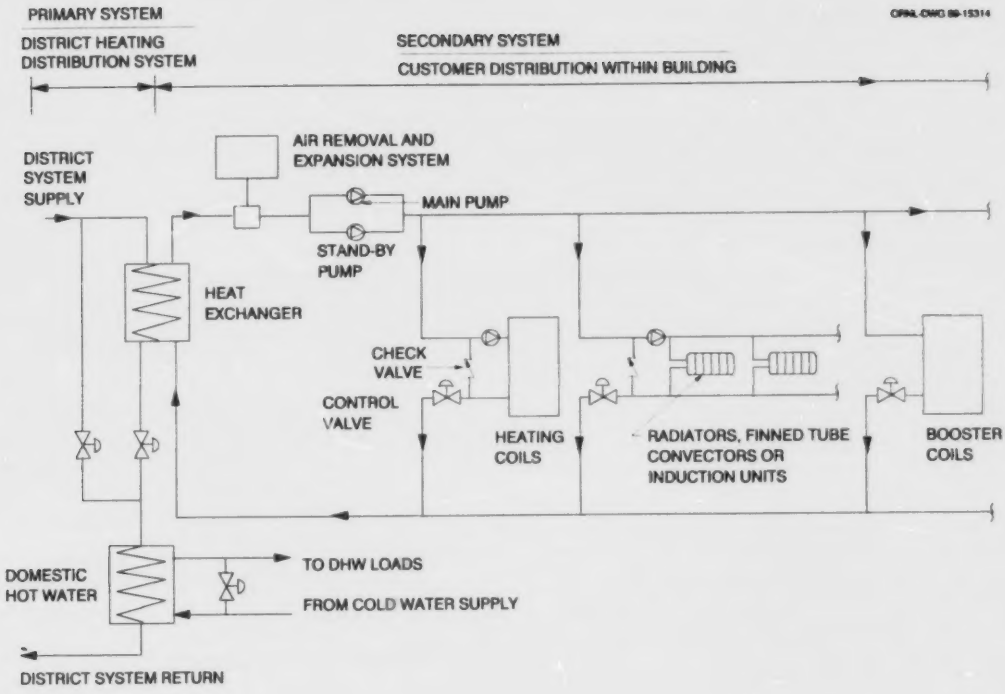


Figure 2.4: Basic Heating System Schematic

2.2.2 Heat Source

Many different energy sources can be used for low and medium temperature hot water district heating, including industrial waste heat, geothermal, solar systems and heat pumps, in addition to conventional boilers or cogeneration. A low district heating return temperature enables efficient use of low-grade energy sources. Lower temperature return water is able to absorb more thermal energy from these sources.

Cogeneration is more efficient and cost effective when low or medium temperature hot water rather than steam is used as the distribution medium. The lower temperature allows a lower turbine back pressure and therefore a higher electrical output and generation efficiency. For example, Figure 2.5 illustrates the relationship between electricity production and heat production for a specific turbine based on the indicated steam data. This example shows that 37% (0.52/0.38) more electricity can be produced if 190°F (88°C) hot water is required for distribution rather than 15 psig (103 kPa) steam or hot water at 250°F (121°C). This percentage will be different depending on the specific turbine, steam and hot water parameters.

Because electric generation is significantly reduced when higher temperature hot water (or steam) is required, cogeneration plants are normally sized only for the base load, with peaking boilers used for elevating the temperature when needed.

The heat source can be either directly connected to the distribution system or indirectly connected through a heat exchanger. The direct system is limited to use where water is the distribution medium and where the water quality and pressure requirements are the same for the heat source and the distribution system. Indirect connection allows the heat source and distribution system to be operated as separate systems with different temperatures and pressures, allowing more design flexibility for both systems.

2.2.3 Distribution

Distribution efficiency increases with an increased temperature differential between supply and return. The thermal capacity of the system is determined by both the rate of water flow and the temperature differential. A large temperature differential allows the use of smaller pipes, which reduces the capital investment for construction of the system.

Figure 2.6 shows the relationship between temperature differential and pipe size. The example illustrated in the figure shows that the pipe size decreases from 24 to 18 inches (610 to 457 mm) when the temperature differential increases from 50°F (10°C) to 90°F (32°C) for a load of 340 MBtu per hour (100 MW). This may decrease distribution capital costs by approximately 30-35%.

2.2.4 Customer Instaliation

It is important that the secondary supply temperature be controlled according to outdoor temperature in a manner similar to the primary supply temperature, based on a curve such as that shown in Figure 2.3.

The secondary system should be designed to ensure a low return temperature, in order to ensure a low primary return temperature. This helps optimize overall system economics and allows customer cost savings through reductions in pipe sizes, smaller

Q_e = ELECTRICAL ENERGY PRODUCTION

Q_h = HEAT ENERGY PRODUCTION

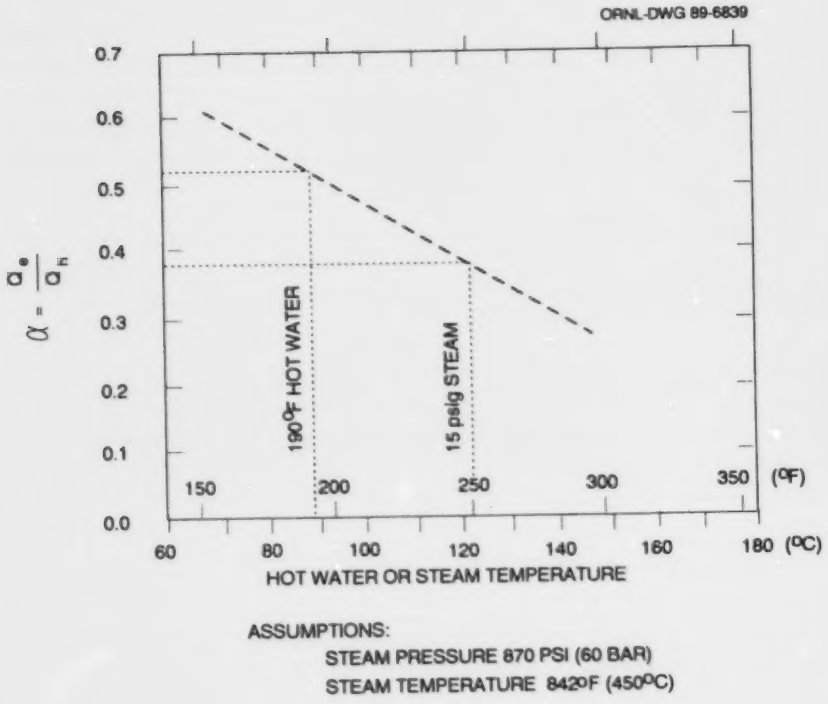


Figure 2.5: Example of Relationship between Electricity Production, Heat Production and Hot Water or Steam Temperature.

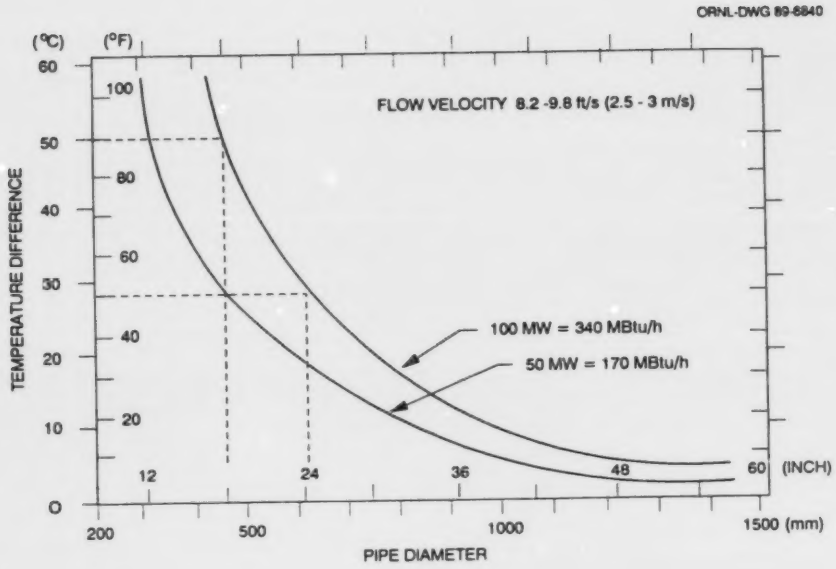


Figure 2.6: Pipe Diameter in Relation to Temperature Difference

pumps, less insulation and smaller pump motors. A reasonable goal for the combined return temperature on the secondary side is 130°F (54°C) or lower. This can be accomplished on most systems, without increasing costs, by proper selection of coils. This goal could be hard to achieve in smaller buildings with only baseboard or radiator space heating.

The flow of water through heating equipment should be controlled according to the heating demand in the space, in order to keep the return temperature low.

2.3 Benefits of Hot Water District Heating

2.3.1 Benefits to the Community

District heating can benefit a community in a variety of ways. It is an excellent thermal load for cogeneration, thereby increasing overall energy efficiency and decreasing environmental problems, including the greenhouse effect. District heating systems also facilitate use of solid fuels such as coal, wood, solid waste or other biomass, since these fuels can be burned efficiently and with appropriate environmental controls in a central facility.

The local economy benefits when local energy resources (solid waste, wood, industrial waste heat, etc.) are used, because energy dollars are recycled in the local economy. Also, the availability of low-cost, convenient heating can help revive older downtown areas, thereby helping draw businesses and the residential population back to the city center.

Energy is saved when a new hot water system replaces an old steam district heating system, due to the efficiency of hot water distribution. Low and medium temperature hot water district heating also allows greater flexibility in the heat sources used, and in some cases allows use of lower-cost piping materials. On the other hand, there are a number of services which are not easily provided with hot water, including humidification, process steam and chilling.

2.3.2 Benefits to the User

Compared to owning and operating an on-site boiler, conversion to hot water district heating can benefit the user through increased reliability, greater tenant comfort, reduced investment, operating cost savings, increased energy efficiency and greater fuel flexibility.

Reliability - District heating systems are built with standby heating capacity to ensure that heat is always available at the central plant. Distribution systems are generally designed with multiple loops or other back-up to provide additional reliability in distribution. Overall, the reliability provided by a properly designed and constructed district heating system is greater than most buildings can achieve on their own.

Tenant Comfort - Hot water district heating provides even heating that is easily controlled, particularly compared to older steam heating systems. The result is greater tenant comfort.

Reduced Investment - In a new building, the owner avoids the cost of purchasing a boiler and associated facilities such as a stack. Owners of existing buildings facing repair or

replacement of the boiler can also avoid these costs. Building space which would otherwise be required for the boiler room can be used more productively.

Building Operation Costs - District heating is a more convenient way to heat a building because it eliminates the need to operate and maintain a boiler facility. This results in savings in staff, administrative, electricity and supply costs. In large buildings the staff savings can be significant.

Esthetics and Environment - Building appearance can be improved because no stack is required. Also, the district heating utility takes responsibility for control of air emissions.

Energy Efficiency - Conversion to district heating can result in substantial energy savings. The user pays only for the heat actually used, whereas a building boiler often operates at a low efficiency. A study of building boiler fuel consumption found that actual seasonal efficiencies averaged 53%, with a range of 42-65%. (1)

Additional efficiency improvements often occur as a result of modifications to the building systems, particularly when converting older steam systems. For example, heat loss in steam traps can be substantial, so elimination of the traps by installing a hot water system will increase overall efficiency, with substantial savings realized in maintenance and operation. While conversion from steam to water distribution can be implemented without converting to district heating, it is always a benefit of converting to district hot water.

Fuel Flexibility - Due to economies of scale, district heating systems can cost-effectively use a variety of energy sources. As a result, many district systems can switch among heat sources depending on what is most cost-effective at a particular time. This flexibility is generally not achievable by individual buildings.

---

(1) Tierney and Fishman, "Real World Boiler Efficiency," presented at the 78th Annual International District Heating and Cooling Conference, June 1987, and "Real World Boiler Efficiency Update," presented at the 79th Annual International District Heating and Cooling Conference, June 1988.

3. DESIGNING FOR INTERFACE WITH DISTRICT HEATING

3.1 Introduction

This chapter describes key points in designing the interface between the building system and the district heating distribution system, and discusses building system design elements that are of relevance regardless of the type of building heating system. This material is intended for use in the design of new building systems as well as for conversion of existing building heating systems.

Section 3.2 describes in detail the elements of the building heat exchanger station required in an indirect connection.

Section 3.3 briefly addresses direct connection of building systems to the district system.

The discussion of secondary systems in Section 3.4 is oriented toward large building systems but is a useful reference for all buildings.

Section 3.5 addresses domestic hot water and Section 3.6 describes radiant floor heat and snow melting systems.

3.2 Building Heat Exchanger Station

3.2.1 Heat Exchangers

Many district heating utilities select and/or approve heat exchangers to be used by customers, and sometimes actually provide the exchangers. In any event, it is essential that the exchangers be carefully selected based on a temperature differential and pressure differential which is compatible with the specific district heating system as well as with local codes.

Reliability is increased if two heat exchangers (each designed for about two thirds of the load) are installed for space heating. One heat exchanger can carry the full load for 80-85% of the heating season, but if both exchangers are operating continually, the return temperature can be reduced. Having multiple heat exchangers in the building is more important if gasketed exchangers are used, and is less important when the utility stocks back-up exchangers for use by customers in emergencies.

When heat exchangers are connected in parallel for uniform load (see Figure 3.1), balancing valves may not be needed. However, isolation or shut-off valves are required for preventive maintenance and emergency work.

There are several types of heat exchangers designed specifically for interface with hot water district heating. Plate heat exchangers generally have a cost advantage and require less space compared with most standard shell and tube (S&T) exchangers. They require one third to one half the surface of S&T units for the same operating conditions because they have higher heat transfer rates. With plate exchangers, the approach temperature between the primary return and the secondary return is closer, generally about 4°F (2°C), compared with about 12°F (7°C) for most S&T exchangers.

An exception to these generalizations about S&T heat exchangers is the spun tube type. This is a S&T heat exchanger with tubes spun in spirals instead of being straight or U-shaped. The spun tube exchangers do not share the disadvantages of other types of

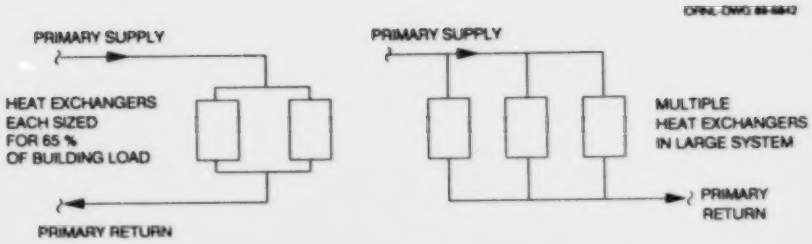


Figure 3.1: Principal connection methods for uniform flow.

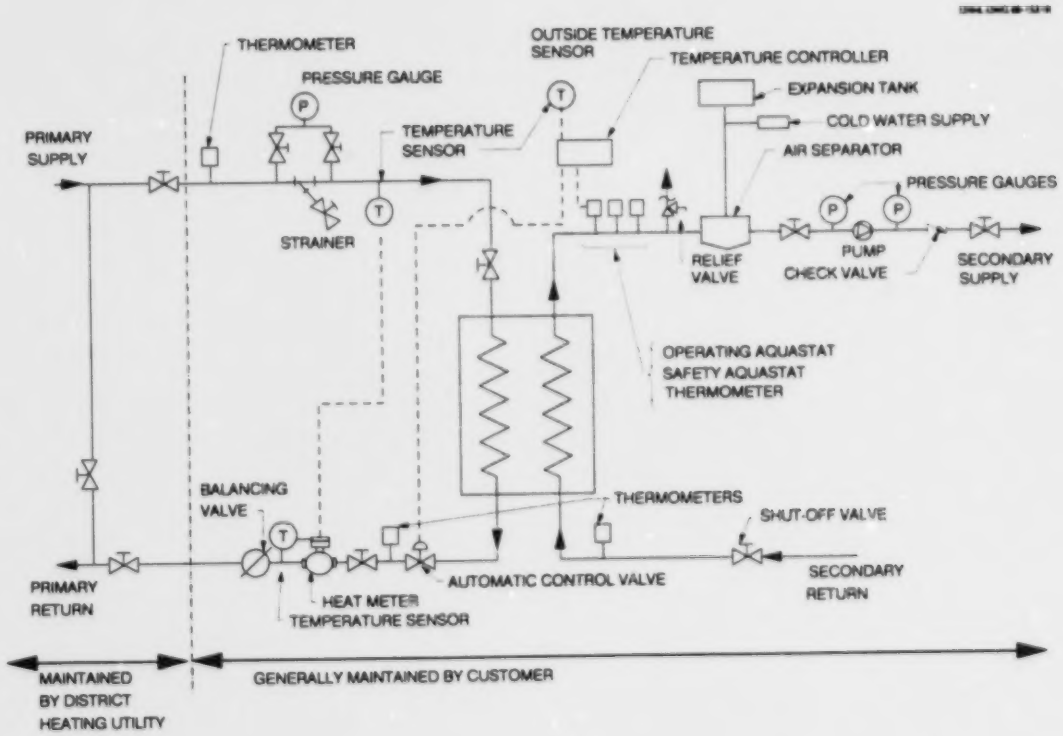


Figure 3.2: Heat exchanger and associated components

S&T exchangers, and are excellent for district heating applications. These exchangers are comparable to plate exchangers and have low fouling resistance and high turbulence for high heat transfer. This type of heat exchanger has no gaskets, so they require less maintenance than gasketed units.

It is essential that plate heat exchanger gasket material be selected specifically for district heating applications, because gasket replacement is costly. Major plate heat exchanger manufacturers have been using special gasket curing methods to improve performance under the temperature variations found in district heating. (See Section 5.2.)

Some manufacturers are producing an all brazed heat exchanger. Since the unit can't be opened, no gaskets are needed. As a result, these units require only minimal maintenance.

Pipe strainers should be installed with all plate exchangers to protect them from grit and debris. Fouling factors for heat exchangers are addressed in Section 5.2.

Special heat exchanger requirements for domestic hot water heating are discussed in Section 3.5.

3.2.2 Temperature Controls

Most hot water district heating systems are designed so that primary and secondary water temperatures vary according to the outdoor temperature. This control method will reduce energy costs and optimize conditions for the control valves, while maintaining comfortable interior temperatures. The outdoor reset and other key control elements for a typical heat exchanger station are shown in Figure 3.2.

Generally, only one control valve is installed, but, if the single valve required is large (2.5 inches or bigger), it is advisable to use two valves connected in parallel and operating in sequence. For best control in most cases, the two valves should be sized to handle one-third and two-thirds of the total capacity. When redundancy requirements are high or equal loads are desired for all exchangers, it may be advantageous to install separate control equipment for each heat exchanger.

Electronic control valves should remain in a fixed position upon power failure, and should be operable manually. Pneumatic control valves should close upon loss of air pressure. A manual override on the control valves will provide the operator the option of controlling the flow.

Temperature sensors should be located by the exchangers being controlled rather than in the common pipe. Improperly located sensors will cause one control valve to open and others to close, resulting in unequal loads in the exchangers.

It is imperative that the heat exchanger control valves be selected to match the building loads. Oversizing will reduce valve life and cause valve hunting. Control valves should be selected with high rangeability, low leakage, and proportional plus integrating control for close adjustment, balancing, temperature accuracy and response time. Control valves should have enough power to open and close under the maximum pressure differential in the system, and should be selected to perform well with the characteristics

of the heat exchanger.

The utility should supply information about the normal pressure differential range at each building. For good controllability and economical selection, the control valve should have a pressure drop through the valve equal to at least one half the pressure drop between the primary supply and return lines. The relationship between valve travel and heat output should be linear, with an equal percentage characteristic.

Control valves are normally installed in the return line because the lower temperature in the line reduces the risk of cavitation and increases valve life. Control valves are for temperature control; they are not intended to be used as pressure reducing valves.

Primary control valves are the most important single element in the interface with the district heating system, and proper valve adjustment and calibration will save energy. High quality, industrial grade control valves should be selected for more precise control, longer service life and minimum maintenance.

3.2.3 Heat Meters

Introduction (1) - The heat meter registers the quantity of energy transferred from the primary system to the user's secondary system. Heat energy is the product of mass flow, temperature difference, the specific heat of the water, and time. It is difficult to measure mass flow in an enclosed pipe system, so volume flow is measured. The result is corrected for the density of the water, which depends on its temperature. The effect of pressure is so small that it can be neglected.

A heat meter consists of a flow meter, a pair of temperature sensors, and a heat calculator which integrates the flow and temperature data.

Meter Types - Following are brief descriptions of the most common flow meters suitable for district heating use. Meters can be divided into two major groups: dynamic meters, which register flow with the aid of moving parts; and static meters, which have no moving parts.

1. Dynamic Meters

There are two types of dynamic meters used in district heating: impeller and turbine meters.

Impeller meters measure flow with the aid of straight-bladed impellers. There are two types of impeller meters: multi-jet and single-jet.

Multi-jet impeller meters are very sensitive to impurities such as sand and sharp metal particles, but are not sensitive to flow disturbances. This type of meter is best suited to medium-sized buildings but not for small buildings because it does not function well at small loads.

---

(1) The discussion of heat meters, particularly meter types,draws extensively from "Small Heat Meters," by Kimari and Sdunzig, Report of Experts' Group on Heat Meters, International Energy Agency District Heating Project, May 1988.

In single-jet impeller meters the flow runs through a single nozzle directed tangentially to the impeller blades. Single-jet meters have properties similar to those of multi-jet meters, but they are more suitable for small buildings because a very weak flow is enough to start the meter.

In a **turbine meter** the flow is always in the direction of the rotor shaft. "Woltmann" and "rotary vane" meters are types of turbine meters. The accuracy of the meter depends on the flow profile before the meter, so strong flow disturbances must be avoided. The flow is directed to the rotor blades via fins.

The weaknesses of this meter are its high start-up threshold and rapid wearing of bearings at high loads and in dirty water. Turbine meters are suitable for high flows, but are not suitable for small buildings.

2. Static Flow Meters

There are two types of static flow meters which are used in district heating applications: magnetic induction (MID) and ultrasonic.

The **MID meter** is based on induction of voltage in a conductor moving in a magnetic field. The conductor in this case is water. Generally, district heating water is conductive enough for MID metering. However, it is essential that this be confirmed in each specific case.

The water flows through a pipe made of non-magnetic material with an exactly known cross-sectional area. The flow is sensed by electrodes connected to powerful electromagnets. The voltage induced in the water is measured and amplified and the information is converted by the heat calculator.

Experience with MID meters in district heating has been good. Although their initial cost is higher than dynamic meters, consideration should be given to their reduced maintenance and increased accuracy.

Ultrasonic metering is based on changes in the propagation of ultrasonic waves caused by the velocity of the flow. These changes are registered by measuring the time between the transmission and reception of ultrasonic signals over an exactly known distance, or by measuring changes in the frequency of reflected ultrasonic waves.

Recent experience indicates that ultrasonic meters are accurate and cost-effective for large flows.

Designing for Meter Installation and Maintenance - The meter is normally installed in the primary return pipe (see Figures 3.2 and 3.3). In this position, the meter is not exposed to high primary temperatures, which affects meter life. In most cases, to ensure uniform flow and accurate flow measurements, there should be a length of straight pipe 10 times the pipe diameter before the flow meter, and a length of straight pipe five times the pipe diameter after the flow meter. The district heating utility and meter manufacturer should be consulted for specific instructions.

Flow meters should not be installed in the low point of the piping system, where

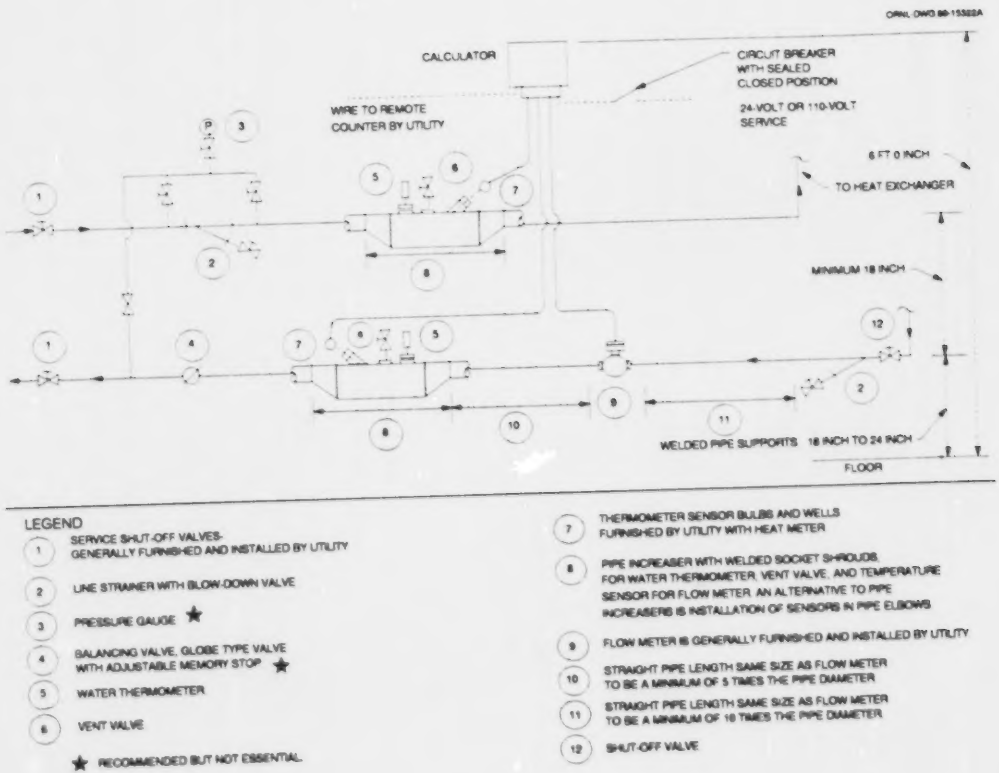

ORNL DWG 89-15382A
CALCULATOR
CIRCUIT BREAKER WITH SEALED CLOSED POSITION
24-VOLT OR 110-VOLT SERVICE
WIRE TO REMOTE COUNTER BY UTILITY
6 FT 0 INCH
TO HEAT EXCHANGER
MINIMUM 18 INCH
WELDED PIPE SUPPORTS
18 INCH TO 24 INCH
FLOOR
LEGEND
1 SERVICE SHUT-OFF VALVES-GENERALLY FURNISHED AND INSTALLED BY UTILITY
2 LINE STRAINER WITH BLOW-DOWN VALVE
3 PRESSURE GAUGE ★
4 BALANCING VALVE, GLOBE TYPE VALVE WITH ADJUSTABLE MEMORY STOP ★
5 WATER THERMOMETER
6 VENT VALVE
★ RECOMMENDED BUT NOT ESSENTIAL
7 THERMOMETER SENSOR BULBS AND WELLS FURNISHED BY UTILITY WITH HEAT METER
8 PIPE INCREASER WITH WELDED SOCKET SHROUDS FOR WATER THERMOMETER, VENT VALVE, AND TEMPERATURE SENSOR FOR FLOW METER. AN ALTERNATIVE TO PIPE INCREASERS IS INSTALLATION OF SENSORS IN PIPE ELBOWS
9 FLOW METER IS GENERALLY FURNISHED AND INSTALLED BY UTILITY
10 STRAIGHT PIPE LENGTH SAME SIZE AS FLOW METER TO BE A MINIMUM OF 5 TIMES THE PIPE DIAMETER
11 STRAIGHT PIPE LENGTH SAME SIZE AS FLOW METER TO BE A MINIMUM OF 10 TIMES THE PIPE DIAMETER
12 SHUT-OFF VALVE

Figure 3.3: Typical installation for heat meter. (No scale)

dirt accumulates. Similarly, they should not be installed in the piping at the high point of the system, which would cause air to accumulate in the meter. To reduce wear on the bearings of a dynamic meter, it is important to fit the meter so that its impeller shaft is vertical. For magnetic meters the pipes have to be grounded. Signal cables should be well protected from external disturbances.

Temperature sensors should always be installed against the flow, with the tip of the probe approximately in the center of the pipe. In addition, a properly sized measurement housing for the sensor and the water thermometer should be installed in the primary piping. Pipe increasers or a measurement housing will not be needed when sensor wells can be installed in pipe elbows or when pipe diameters exceed 4 inches (about 100 mm). In smaller pipes, wells for heat meter sensors can obstruct the flow. The sensors' surroundings should always be heat-insulated; otherwise heat loss from the sensors distorts the measurement. The sensors' wires should be of exactly the same length unless four-wire metering is used.

An MID meter should be fitted so that it is as easy as possible to clean the pipe and electrodes. Dirt on the electrodes creates an extra resistance which causes errors in the voltage measurement.

MID meters are not very sensitive to flow disturbances. Manufacturers state that a disturbance-free section of pipe five times its diameter before the sensor is enough, and they recommend that a pipe section two times its diameter should be free from disturbances after the sensor. However, any meter is more accurate if the disturbance-free sections of pipe are longer than the recommended minimums.

Meters are generally supplied and installed under the supervision of the utility company. The utility may also supply a temporary spool, the same size as the meter, for installation in lieu of a meter until the system is clean and ready for operation. Meters will be sized by the utility in accordance with information supplied by the mechanical engineer for the building system. For proper meter selection, it is essential that the utility understands the building system operations under maximum and minimum flow conditions.

3.2.4 Other Equipment

Pressure gauges, thermometers and shut off valves should be installed to enable proper monitoring, balancing and equipment isolation for maintenance. (See Figure 3.2.) A balancing valve should be installed if deemed appropriate by the district heating utility.

A strainer with a mesh of 1/24 to 1/16 inch (1.0 to 1.6 mm), preferably the smaller size, should be installed. In order to determine when the strainer should be cleaned, a pressure gauge should be connected to both sides of the strainer (see Figure 3.3). The pressure drop through the strainer must be considered in the system design. If necessary, a larger diameter strainer should be considered so that the flow is not restricted.

3.2.5 Location of Heat Exchanger Station

The utility should be consulted as to the location of the building heat exchanger station because this will determine the location of the primary system piping. The room size should meet the local building code, and the equipment should be accessible for inspection and maintenance, including disconnection and removal of equipment for repair or replacement. Personnel from the utility must be able to enter the room unassisted, but the room should be locked to keep out unauthorized personnel.

3.3 Direct Connection

Direct connection of the customer's terminal heating equipment (such as heating coils, radiators, unit heaters, etc.) to the primary distribution system is in some cases more economical than the indirect method. No heat exchangers, pumps or water treatment systems are required in the customer installation, thereby reducing the investment costs. There is also a potential for getting a somewhat lower district heating return temperature. Direct connection should especially be considered in new development areas where building heating systems could be designed for direct connection.

When designing a direct system, care must be taken to protect the safety of the customer installation and the reliability of the district heating system. Direct connection increases the opportunities for damage or contamination which could affect the entire system.

In a direct system, the main distribution system pressure has to be selected to meet the local building codes. The pressure differential in the distribution system changes with the load and with distance from the heating plant, and is sometimes larger than desired within building systems. To minimize noise and control problems, a constant pressure differential control valve should be installed in the buildings.

Normally, the district system supply temperature is the same as that required in the buildings. Figure 3.4 shows the simplest form of direct connection, which includes a pressure differential regulator, a thermostatic valve on each heating unit, a pressure relief valve and a check valve. Special attention should be given to potential noise problems at the thermostatic valves. These thermostatic valves must be specified to correspond to the design pressure differential.

If the temperature in the main system is higher than required in the building systems, there is a potential for a larger temperature differential between supply and return, which reduces the required pipe size. Desired supply temperature within the building is then accomplished by mixing return water with supply water. This approach, illustrated in Figure 3.5, requires a centralized temperature control system with a temperature controller connected to an outdoor temperature sensor.

Depending on the size and design of the main system, elevation differences, types of customers and building systems, additional safety equipment such as automatic shut-off valves on both supply and return lines may be required.

Most North American hot water district heating systems serving large buildings will be the indirect type because the diversity in building elevations and pressure limits in existing buildings will make direct systems impractical.

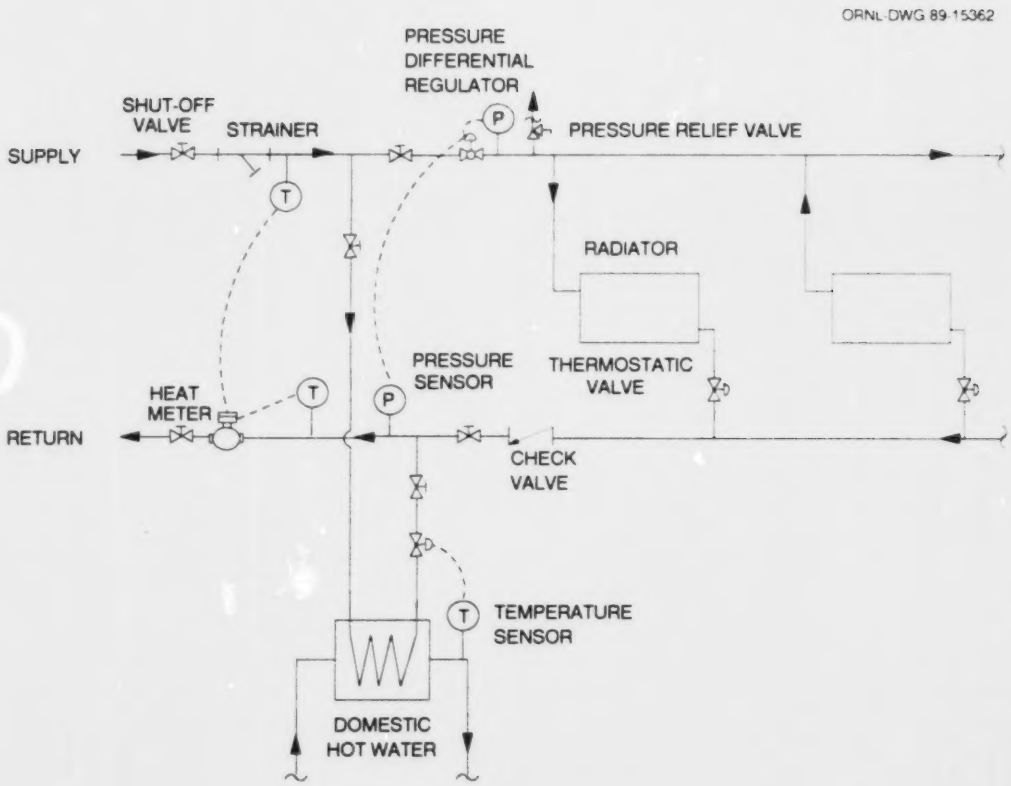


Figure 3.4: Direct Connection of Building System to District Hot Water

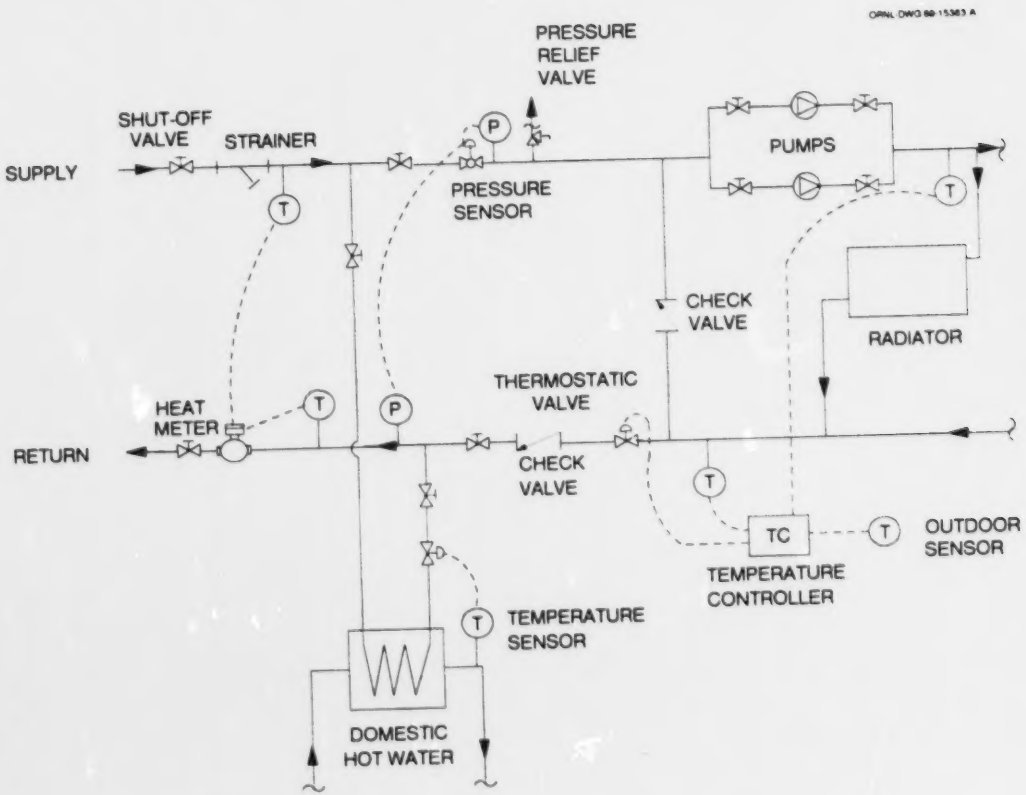


Figure 3.5: Direct Connection with Recirculation

Direct connection is most suitable for smaller district heating systems and/or where the static head in the distribution system is low, which is the case in areas with relatively flat ground and low buildings. The feasibility of direct systems is also enhanced where most of the buildings to be served are designed and built with direct district heating in mind.

This brief discussion of direct systems is provided only as an overview. Although no further discussion specifically addressing direct systems is provided, most of the following guidelines are also applicable to direct systems.

3.4 Secondary Systems

3.4.1 General Considerations

Unless the district heating system is designed for direct connection, primary water should not be used directly in radiators and other terminal heating units. The building heating system should be isolated by a heat exchanger from the district system.

Secondary systems can be separated by pumps serving sub-circuits that supply different terminal equipment, areas or buildings, but are connected to the same heat exchanger (see Figure 3.6). If a system is spread out, booster pumps may be required in remote locations. Different groups of terminal equipment and/or air handlers can be arranged for different temperature demands (see Figure 3.7).

When sub-circuits in the secondary system are located close to the heat exchanger(s), the main secondary system can be arranged without main circulating pumps, as shown in Figures 3.6 and 3.7. There is usually no advantage in separating ventilating and space heating loads into separate systems with separate heat exchangers. Separate systems may be advantageous only when temperature requirements differ considerably. In such a case, care must be taken to ensure that the temperature of the combined return water from all systems is low enough to satisfy the minimum requirements of the primary distribution system.

When thermostatic (self-contained) radiator valves are used, the radiator circuit should be designed with as low a pressure differential as possible to avoid problems with noise and leaking valves.

To ensure that water is circulating and available for morning startup, a small bypass valve between supply and return can be installed in remote locations (see Figure 3.6) according to the design engineer's judgement. If the system is large and extensive, then there is no need for such a bypass. This is because with many terminal units, some will always be calling for heat. The valve should not be larger than 3/4 inch (19 mm) and should be adjusted for the minimum flow required to keep pipes hot (usually 0.5% of the normal end-circuit total flow rate). A thermostatically regulated valve may be incorporated into the bypass. The valve temperature setting should be about 95°F to 105°F (35°C to 40°C).

The sub-circuit supply water temperature is controlled by increasing or decreasing the secondary supply water temperature. The temperature is reset from the outdoor temperature (see Figure 3.8), based on a curve such as that shown in Figure 3.9. The sub-circuits operate with a constant flow rate. Balancing valves should be installed for each

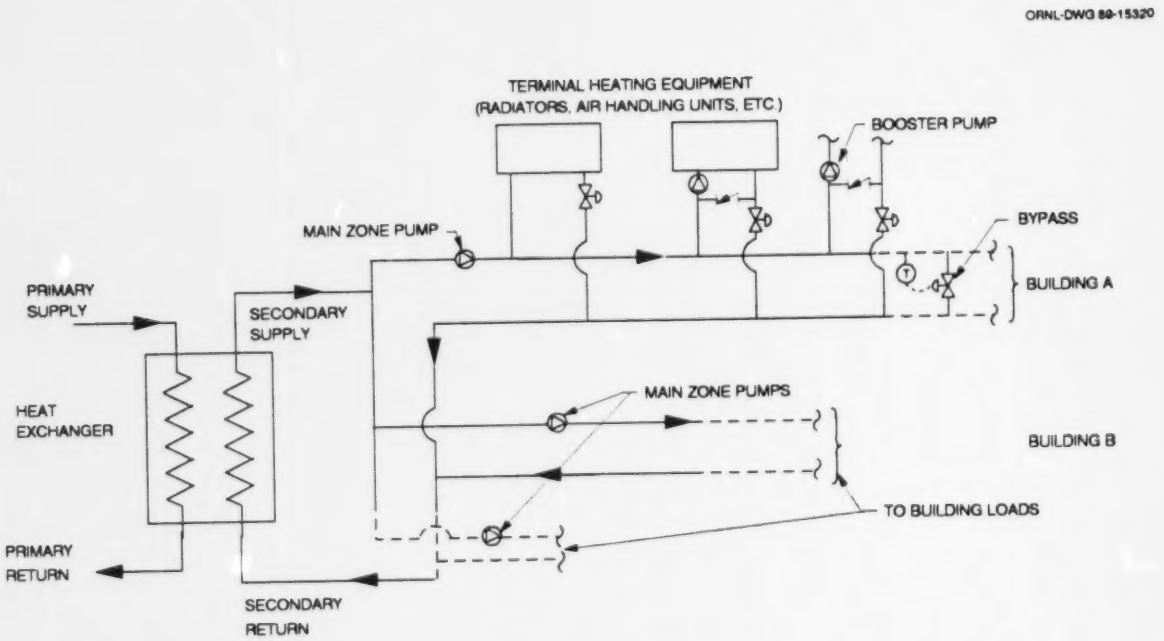


Figure 3.6: Heating system with several sub-circuits and distribution pumps

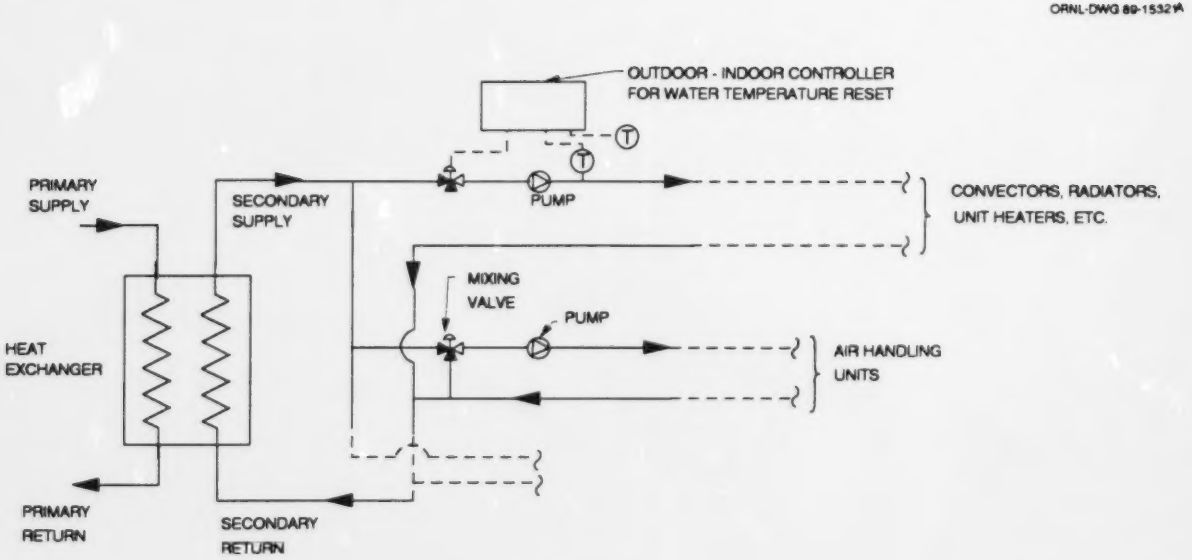


Figure 3.7: Heating system with multiple sub-circuits having different temperature demands.

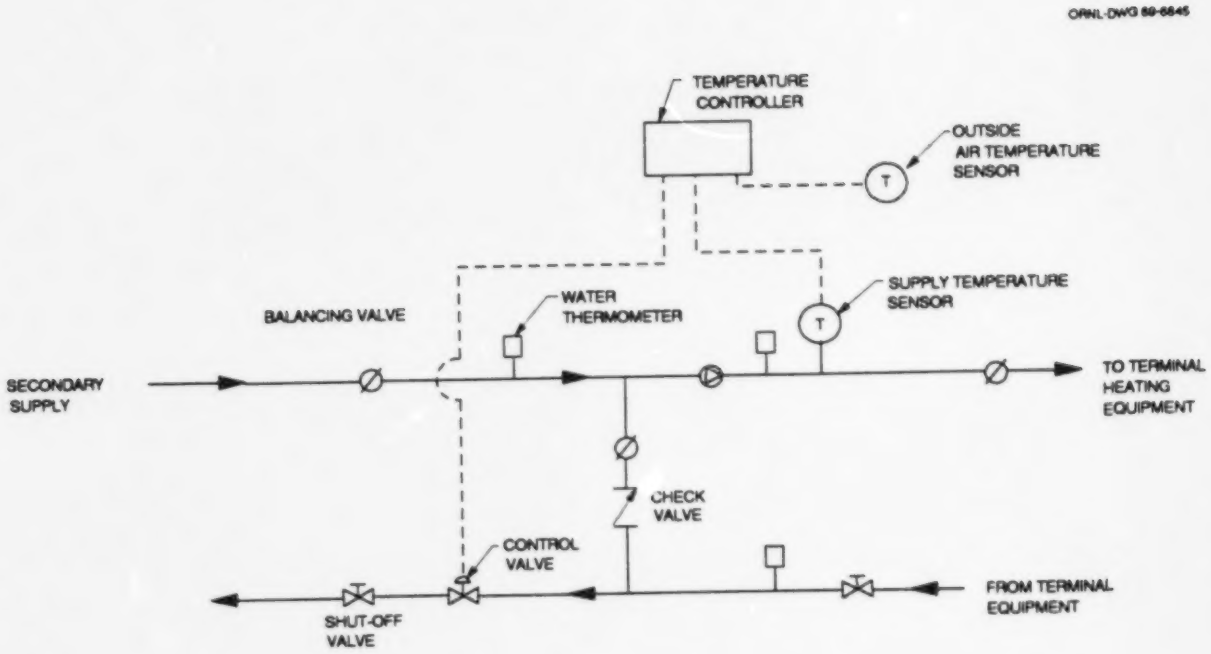


Figure 3.8: Typical Sub-circuit Pumping System

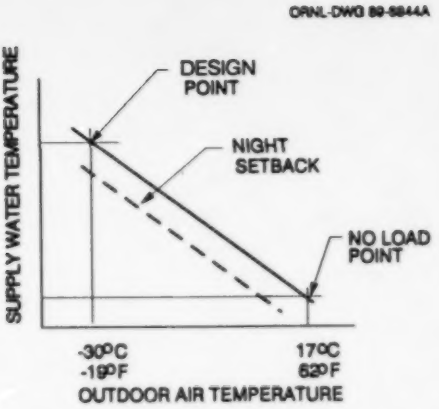


Figure 3.9: Typical Outdoor-Indoor Controller Curve for Space Heating Equipment

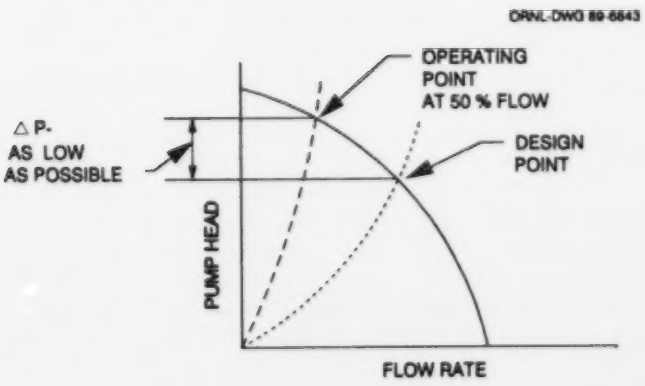


Figure 3.10: Pump characteristics at 50% flow rate

sub-circuit on the risers to balance the main secondary system.

Energy can be saved in some buildings by reducing the supply water temperature or cycling the pump from the night thermostat during unoccupied hours. This can be automatically controlled through the temperature controller. Ventilation can be shut off while the perimeter radiation is used to provide the space heating required.

3.4.2 Distribution

Two distribution pumps are normally installed, with one acting as a standby for the other. The pumps are usually shut down during the summer when no heating is required, but some small loads may still require heat (e.g. domestic water heaters if served by the same heat exchanger). A small pump can be installed to serve these units rather than using the larger pumps. Smaller pumps might also be advantageous in buildings where large loads are shut down on nights and weekends.

Pump heads must be calculated carefully because over-sized pumps negatively affect valve controllability. Pressure drop in the system should be limited, especially if thermostatic valves are used. Flat pump curves should be chosen to prevent the system pressure from rising during low use conditions. If a steep pump curve cannot be avoided, a bypass valve can be installed. A pressure differential sensor can be used to control the valve and bypass water around the pump(s) to maintain a proper pressure differential (see Figure 3.10). The pressure sensor can be located between the supply and return pipes near the pump(s) or anywhere in the system to maintain pressure at a set value.

"Safety factors" should be avoided in control valve selection calculations, because over-sized valves can lead to poor performance. When the most remote control valve has been sized, the pressure drop in the system is obtained by adding the drop through the pipes, bends, valves, heat exchangers and terminal equipment (if the latter do not have circulating pumps of their own). The pressure drop for control valves serving air handling units and water heaters is normally selected to be equal to or greater than the pressure drop through the heating elements.

For larger buildings with hydronic heating systems, a variable speed pumping system should be considered. Building heating systems designed with two-way valve controls on the heating elements work well with variable speed pumping systems.

Variable speed pumping may cost more initially, but it saves energy and wear on the mechanical system. The benefits of variable speed pumping have been demonstrated in many systems, and include: higher design flow velocities; improved air elimination due to low flow velocity most of the time; and elimination of balancing devices for pumps, sub-circuits and each heating element due to better controllability. Because all heating elements are specified with control valves, the valves will apportion the water to the elements according to the heating load. Variable speed pumping systems will compensate for overheadings and overdesign for future load conditions.

3.4.3 Heating and Ventilation Equipment

General Considerations - As emphasized in Chapter 2, low return water temperature is an important design goal. Table 3.1 shows common design temperature objectives for primary and secondary systems serving various types of heating equipment.

Temperatures in a specific case will depend on the supply temperature of the district heating system and other site-specific factors.

TABLE 3.1

COMMON DESIGN TEMPERATURE OBJECTIVES FOR HEAT EXCHANGERS

	Primary Side				Secondary Side			
	Supply		Return		Supply		Return	
	°F	°C	°F	°C	°F	°C	°F	°C
Combined System*	250	(121)	140	(60)	175	(79)	130	(54)
Radiators	250	(121)	150	(66)	175	(79)	140	(60)
Heating Coils	250	(121)	125	(52)	175	(79)	105	(41)
Booster Coils	250	(121)	150	(66)	175	(79)	140	(60)
Reheat Coils	170	(77)**	125	(52)	140	(60)	105	(41)
Floor Heating	170	(77)**	140	(60)	130	(54)	110	(43)
Snow Melting	125	(52)+	105	(41)	130	(54)	90	(32)
Domestic Hot Water	170	(77)**	80	(27)	130	(54)	50	(10)***

*For example, a system which includes both radiators and coils.

** This minimum summer primary supply temperature may be higher than 170°F (77°C), depending on customer requirements. For example, some industrial process loads or other loads may require that the summer temperature is at least 190°F (88°C) or higher.

*** Or local cold water supply temperature.

+ 125 to 150°F (52 to 66°C) primary return water is usually used. In some installations, primary supply water is combined with return water to meet the peak demand.

A secondary return temperature of 130°F (54°C) is usually easily achieved in buildings with heating coils in the ventilation systems, but can be more difficult if space heating is provided entirely by radiation equipment. Variable flow or scheduled water temperature in the secondary system is an important element in achieving low return temperatures.

Air Handling Units - Air handling units are normally connected directly to the main secondary system (see Figure 3.11). Heating coils in units exposed to potential freezing from outside air should be equipped with a circulating pump. The pump head is calculated for the pressure drop through the coil, piping and valves. The pump should be controlled from the outdoor temperature sensor below 50°F (10°C). A balancing valve must be installed at the pump discharge, since the pump will not have the exact flow rate matching the coil flow.

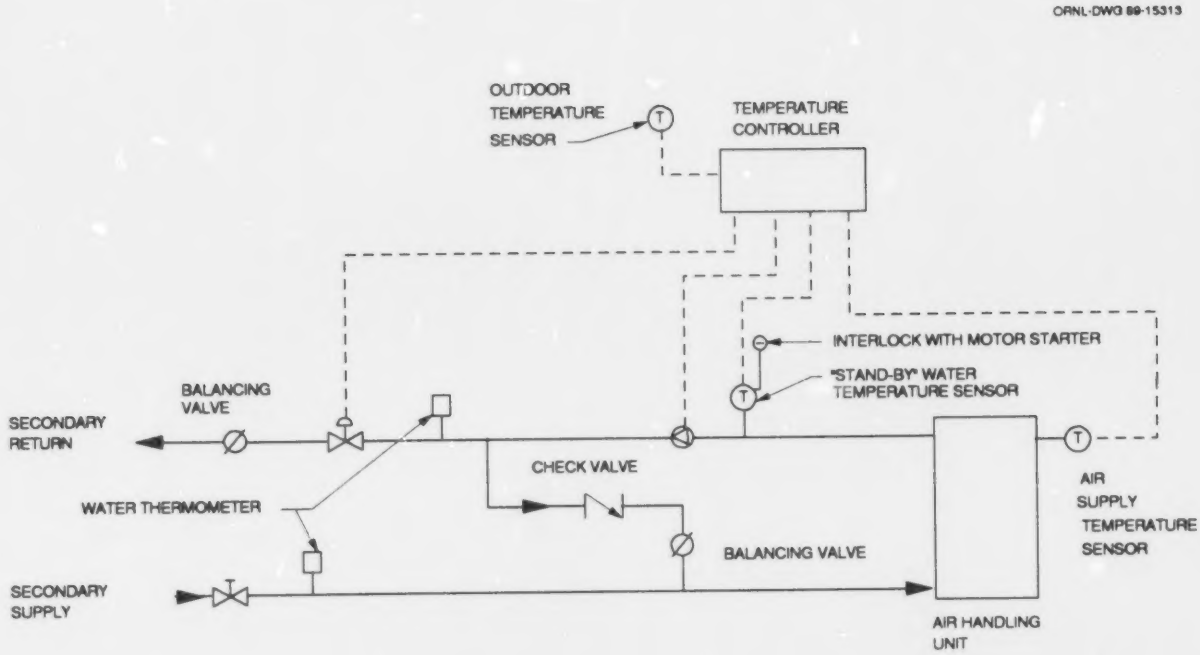


Figure 3.11: Typical Air-Handling Unit with freeze protection

Normally, the coil control valve should be closed when the unit is not calling for heat or when it is shut down at night. To protect the coil from potential freezing, an immersion sensor should be installed in the coil water loop (see Figure 3.11) to open the control valve and maintain the water in the coil at about 100°F (38°C). Where winter air temperatures can drop below freezing, the sensor should be installed for any air handling unit incorporating a heating coil with a fresh air intake. When the unit is off, it is essential that control valves are closed to reduce the possibility of supply water being bypassed into the return line without being cooled.

The importance of freezing protection (in appropriate climates) cannot be over-stressed. Even if a large amount of recirculated air is returned to the system, freezing can occur at shutdown. Air pressure differences within a building will always exist, causing air leakage through dampers and the exposure of coils to outside air.

Coils in multi-zone and dual duct units should be controlled by an air supply temperature sensor reset from the occupied area with the greatest heating demand. This will reduce energy requirements, ensure a low return temperature from the heaters, and increase air flow in the hot air duct at low heat demands. Increased air flow is a favorable operating condition for the mixing boxes.

Booster coils or reheat coils are usually connected directly to the main secondary system. The control valve should be closed when the coil is not calling for heat. Design temperature objectives are suggested in Table 3.1. Generally, the water temperature difference should not be less than 30°F (17°C).

Unit heaters should be equipped with automatic or solenoid shut-off valves if no other control valves are installed. Shut-off valves will prevent water from returning without being cooled if the fan is not running. A solenoid valve is normally connected to the fan contactor.

3.4.4 Water Treatment

In a closed water loop with minimal make-up water requirements, chemical water treatment is limited to neutralization of corrosive properties and control of scaling in heat exchangers.

3.4.5 Expansion System

A water expansion system should be installed for every closed loop system. Any standard method, such as an enclosed pressure vessel, can be used.

Air removal should be considered in the design. When air is separated from water at the hottest point in the system, water supplied to the building systems will be free of air.

3.5 Domestic Hot Water

3.5.1 General Considerations

Domestic hot water (DHW) temperature should be set according to local codes, generally between 120°F and 140°F (49°C and 60°C). A water temperature of 180°F (83°C) is often required for kitchen or laundry equipment, and this can be generated when the primary

water temperature is 190°F (88°C) or higher. If necessary, electric booster heaters can be used to serve high temperature loads such as process heat.

Return water from the space heat exchangers may be used to heat DHW. To ensure adequate capacity when the space heating demand is low, the DHW heat exchanger should be connected to the primary supply in parallel with the space heat exchanger (see Figure 2.4).

In buildings with a relatively large DHW demand, a pre-heater can be used. In this approach (Figure 3.12), DHW is pre-heated by return water from the space heating system. In addition to reducing the primary return temperature, this approach reduces lime build-up in the heat exchanger, extends equipment life and reduces maintenance costs. When there is no space heating load, another heat exchanger (post-heater) using primary water can provide DHW.

If DHW demands are limited (such as in office buildings without kitchens or recreational facilities), it may not be feasible to use return water. In such cases, all heat exchangers are connected in parallel directly to the primary supply. In some situations, electric water heaters may be the most cost-effective solution to some or all of the DHW heating requirements.

3.5.2 Domestic Hot Water Heat Exchangers

The DHW heat exchanger should always be selected with a fouling factor based on the local water quality. A suggested minimum fouling factor if 0.002 square foot per °F per Btu per hour (0.004 square meter per °C per Watt), including both the primary and secondary sides. An adequate fouling factor is especially important with higher DHW temperatures.

Some local codes require DHW heaters connected directly to the primary supply to be the double wall type, with the separation vented to the atmosphere. In these cases, DHW can be heated in the following ways:

1. Tube-Within-a-Tube Heat Exchanger
In this double-wall heat exchanger, the inner tube contains potable water and the outer tube is surrounded by the primary district heating water. A leak from either tube will enter the void area between the tubes and leak to ambient.

2. Double-Wall Plate Heat Exchanger
The double-wall plate heat exchanger is similar to a conventional plate heat exchanger, except that the single plate between the two media is replaced with two plates. The space between the plates is vented to the atmosphere.

Gasketed plate heat exchangers should be avoided when used as an instantaneous water heater. The extreme water temperature conditions between the heating media and the city cold water will accelerate the expansion and contraction of the plates, resulting in leaks.

3. Sweet Water Loop
Two single-wall heat exchangers can be used with an intermediate fluid circuit (the "sweet-water" loop) that transfers the heat from the primary hot water to the

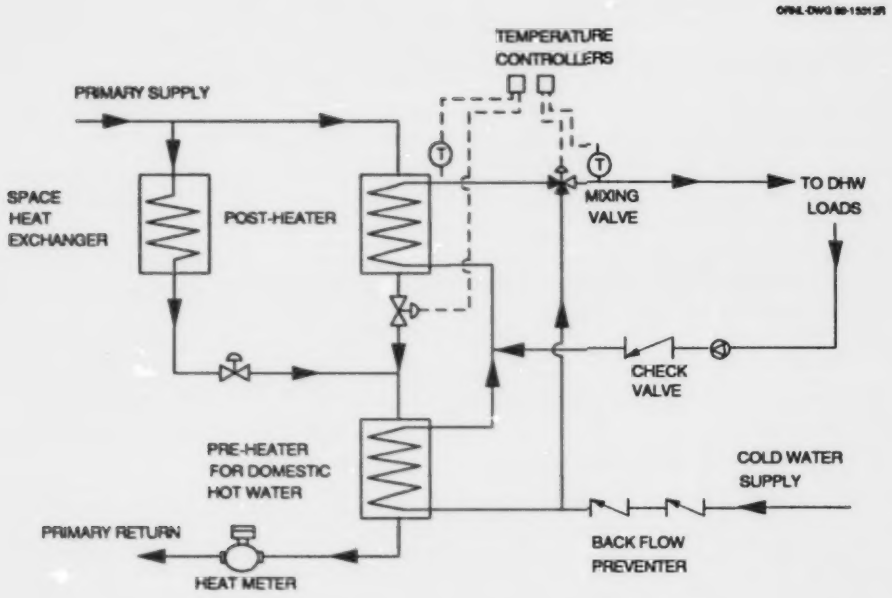


Figure 3.12: Domestic Hot Water Heater with pre-heater section (For large Domestic Hot Water users.)

potable water. The intermediate fluid will form the double barrier between the two circuits. Any leak from either circuit would enter the intermediate fluid that is passing between the two circuits. The sweet water loop circuit has lower pressure than either the potable system or the primary system (see Figure 3.13).

In most cases, a single-wall heat exchanger may be used on the secondary side of the building heating system with additional safety features required by local codes and the National Sanitary Foundation.

3.5.3 Temperature Control

Depending on the size of the domestic water heater, two temperature control valves may be required, to operate in sequence. The controller sensor, located in the leaving domestic hot water side, should be as close to the outlet of the heat exchanger as possible for quick sensing of leaving water temperature. Since the heat exchanger normally does not have any real storage capacity, the controller must sense all sudden changes in temperature and adjust the control valve without hunting or delay. The controller should be adjustable for between 1 to 100 seconds response time, and should generally be adjusted for quick response (less than 20 seconds).

When heat exchangers are used as instantaneous units without storage tanks, a three-way mixing valve is recommended to reduce the possibility of water scalding. It may be adequate to reduce the temperature of the leaving water from the heat exchanger by mixing it with recirculated hot water.

Electronic control valves can be opened manually, and enable continued domestic water service in the case of power interruption or failure of the control valve. Control valves should be specified to incorporate a manual override on air and power interruptions. Section 5.5 summarizes recommended specifications for control valves.

3.5.4 Storage

In schools, gyms, large kitchen facilities, hotels, commercial laundries, apartment buildings, and hospitals, the instantaneous peak DHW loads are usually from showers, and occur within a short period (generally four hours or less).

In these cases, DHW storage is recommended. A storage tank will help reduce the size of the heat exchanger, thereby allowing a lower recovery rate and smaller piping and control valves. Steel storage tanks should be lined unless they are entirely stainless steel. Tank construction should be studied for compatibility with the water. Caution should be taken when stainless steel is sued in the presence of chlorides or when copper is used in the presence of ammonia.

In sizing storage tanks, 60% to 80% of the tank volume should be considered usable storage capacity. Storage tank size should be increased to compensate for the unusable hot water.

3.6 Radiant Floor Heat and Snow Melting Systems

Floor heat and snow melting systems operate with low temperatures, normally in the range of 90°F to 130°F (32°C to 54°C). Many different pipe materials can therefore be

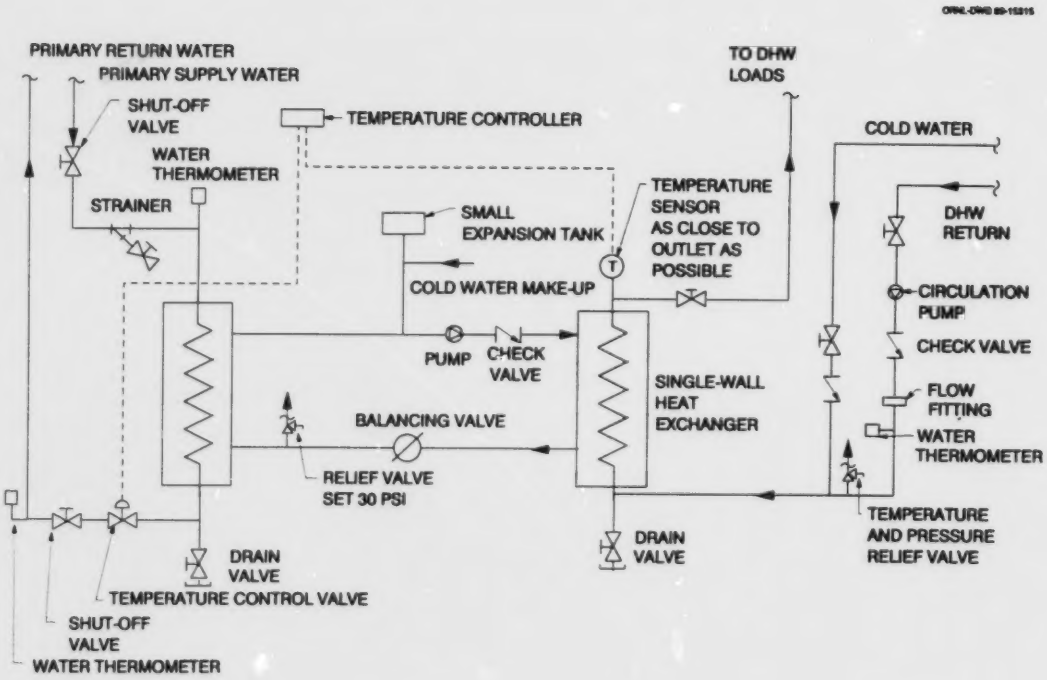


Figure 3.13: Single Wall Heat Exchangers with sweet water loop

considered, such as copper, steel, chlorinated PVC, polybutylene and cross-linked polyethylene. Plastic pipe is most commonly used today for buried pipes due to the corrosion potential with copper or steel pipe. Also, polybutylene and cross-linked polyethylene pipes have the advantage of being more flexible, and are delivered in long lengths, thereby reducing the number of joints, the installation time and the chances for failure.

One limitation of plastic pipe is the diffusion of oxygen through the pipe wall. Generally, plastic pipe should not be installed with steel pipe or other steel components due to the potential for corrosion. Plastic pipe with an oxygen barrier is now available but experience with this pipe is limited.

Due to the low temperature required for snow melting and floor heating systems, primary return water should be considered for the energy source in order to minimize the overall return temperature (see Figure 3.14). If the primary return water temperature or flow is not adequate for peak conditions, heat can be provided from the primary supply water.

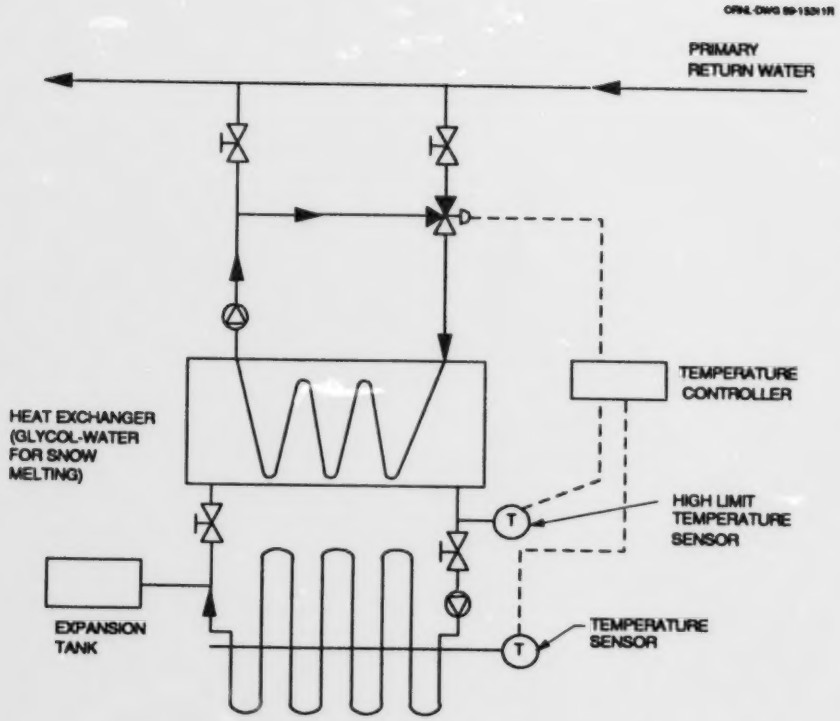


Figure 3.14: Snow melting and underfloor heating systems

4. BUILDING CONVERSION

4.1 Introduction

A building may include one or more of the heating systems types summarized in Table 4.1. Large buildings constructed prior to the early 1950s were generally steam heated. After that period, new heating systems were often a combination of hot water radiation and steam supplied to the air handling systems. In recent years, heating system designs based solely on air handling systems have become more common.

Residences and other small buildings most commonly use: a gas-fired, oil-fired or electric warm air furnace; hot water radiation; or steam radiation. In some parts of North America, air-to-air heat pumps are becoming more common. When considering conversion of small buildings, Sections 4.3 through 4.6 will be of primary interest. Sections 4.2, 4.3.4, and 4.7 through 4.11 are directed toward conversion of large buildings.

TABLE 4.1

HEATING SYSTEM TYPES

1. Steam Systems

Radiation

One-Pipe Cast Iron Radiators - Steam is supplied to cast iron radiators in a single pipe which also provides condensate return.

Two-Pipe Cast Iron Radiators - Steam is supplied to cast iron radiators in a supply pipe, and a separate pipe provides condensate return. Steam traps, which allow for the passage of condensate but not steam, connect the two pipe systems.

Finned Tube Radiators / Convectors - Steam is supplied to heat transfer tubes or pipes with an extended surface of fins, disks or ribs, and a separate pipe provides condensate return.

Air Handling Systems

Coils in Air Handling Units - Steam is supplied to heating coils in air handling units.

Coils in Terminal Units - Steam is supplied to coils in terminal equipment located in each heating zone, such as fan coils, unit ventilators, unit heaters, terminal reheat in ducts, etc.

2. Hot Water Systems

Radiation

Radiators and Convectors - Hot water is supplied to cast iron radiators or heat transfer tubes or pipes with an extended surface of fins, disks or ribs.

Radiant Panel - Hot water is circulated through pipes embedded in the floor or ceiling of the heated space.

Unitary Heat Pumps - Low temperature hot water is circulated to individual water-to-air heat pump units located throughout the heated space.

Air Handling Systems

Coils in Air Handling Units - Hot water is supplied to heating coils in air handling units.

Coils in Terminal Units - Hot water is supplied to coils in terminal equipment located in each heating zone, such as fan coils, unit ventilators, unit heaters, terminal reheat in ducts, etc.

3. Gas/Oil-Fired Systems

Warm Air Furnaces - Gas or oil is burned to indirectly heat air which is then circulated through ducts to the heated space.

Rooftop Units - Gas or oil is burned in units mounted on the roof, to directly or indirectly heat air which is then discharged into the room below or through a short duct.

Other Systems - This category includes radiant or infrared heaters, duct heaters, unit heaters, etc.

4. Electric Systems

Electric Resistance Furnaces - Electric resistance elements are used to directly heat air which is then circulated through ducts to the heated space. (Generally used in homes or other small buildings.)

Rooftop Units - Electric resistance elements are used to directly heat air which is then discharged into the room below or through a short duct.

Air-to-Air Heat Pumps - A fan unit with a refrigeration system is used to transfer heat into a space; the condenser heats the space while the evaporator extracts heat from outdoor air. During summer, the system is reversed to cool the space and reject heat to the outdoors.

Other Systems - This category includes duct heaters, unit heaters, radiant panels, baseboard electric heaters, etc.

Generally, hot water systems are relatively easy to convert to district heating. Conversion of one-pipe steam systems, gas/oil-fired systems or electric systems are generally more difficult and costly. The relative suitability generally found for each heating system type is summarized in Table 4.2. However, it is important to note that site-specific factors can result in differences from these generalizations for a specific building.

TABLE 4.2

CONVERSION SUITABILITY OF HEATING SYSTEM TYPES

	Low	Medium	High
1. Steam			
Radiation			
One-Pipe Cast Iron	X		
Two-Pipe Cast Iron		X	
Finned Tube		X	
Air Handling Systems			
Coils in Air Handling Units		X	
Coils in Terminal Units	X		
2. Hot Water			
Radiation			
Radiators and Convectors			X
Radiant Panel			X
Unitary Heat Pumps			X
Air Handling Systems			
Coils in Air Handling Units			X
Coils in Terminal Units			X
3. Gas/Oil-Fired Equipment			
Warm Air Furnaces	X		
Rooftop Units	X		
Other Systems	X		
4. Electric Equipment			
Electric Resistance Furnaces	X		
Rooftop Units	X		
Air-to-Air Heat Pumps	X		
Other Systems	X		

Section 4.2 presents a general procedure, **primarily for large buildings**, for conducting the conversion evaluation and design. Conversion of specific types of terminal heating equipment and distribution systems within each of the four major categories of building heating system types are then discussed.

4.2 Procedure for Building Conversion

The level of detail presented in the following procedure is appropriate for large buildings, but a much more abbreviated approach can be taken with small buildings. The building heating system conversion analysis is divided into the following steps:

- Survey and schematic design
- Building heating load
- Component compatibility
- Conversion concept and costs
- System optimization and detailed design
- Construction schedule
- Testing and commissioning

4.2.1 Survey and Schematic Design

A complete survey of the heating system should be made. Engineering drawings and specifications are very helpful in tracking down mechanical equipment in a large complex. However, existing drawings should not be completely relied upon. In many cases, previous alterations in the system limit the usefulness of the original documents.

A schematic diagram of the existing system will help in defining the scope of work. Sketches of the building heating system piping help to focus the engineer's attention on each system component. Basic items to look for include:

- Boiler room and piping
- Mechanical rooms throughout the building
- Terminal units, such as radiators, fan coils, etc.
- Air handling units
- Domestic hot water heaters
- Chilling equipment
- Kitchen equipment
- Humidification equipment
- Sterilization equipment

Operating personnel should be interviewed to assess the equipment and system operation. Building operating engineers are familiar with the history of the equipment and all space conditions, such as the proper amount of ventilation and proper heat distribution.

4.2.2 Building Heating Load

The building's energy consumption must be determined, based on historical usage. In estimating future heating requirements, it is important to take into account the energy conservation impact of the conversion to hot water district heating. Peak load must be estimated in order to size the heat exchanger and other components.

The heat exchanger should not be sized based on nameplate capacities of existing boilers or other equipment, because this equipment is usually oversized to begin with, and implementation of energy conservation often accentuates this factor. Over-sized equipment is costly in terms of the initial purchase cost as well as ongoing maintenance, and generally does not provide good controllability.

For many buildings, particularly smaller buildings and/or those with good energy records, peak load can be calculated from energy use records, the degree-day method and a utilization factor.

Fuel use data must be adjusted by a seasonal boiler efficiency factor. A recent study of

boiler fuel consumption found that actual seasonal efficiencies ranged from 42% to 65%, with an average of 53%. (1) Energy use data must be weather-normalized using the degree-day method.

The projected annual energy consumption is then be divided by a "utilization hours" factor to derive a peak load. Utilization hours is a factor which relates the peak energy requirement to annual usage for a given building usage pattern and climate. The district heating utility can provide the appropriate factor.

For larger buildings and/or those with inadequate energy records, calculations for the building envelope block load and the ventilation load can be used to estimate the peak load.

4.2.3 Component Compatibility

The age, condition and heat source of each component of the existing system must be assessed. The design supply and return temperatures of existing heat transfer equipment in a hot water heating system must be checked for compatibility with district heating. The secondary system must be designed to optimize the size of the new components to provide a low hot water return temperature. Equipment can often be used as is or be modified fairly easily to meet requirements.

4.2.4 Conversion Concept and Costs

The proposed conversion concept, designed to meet the specific needs of the building occupancy, is then established. The conversion should be as cost-effective as possible while meeting performance requirements. Re-use of existing equipment is an important element in keeping costs low. Conversion costs should be estimated, including, as appropriate, the following:

- New and/or modified piping
- Heat exchangers for space heating and domestic hot water
- New heating coils or additional heat transfer surfaces
- Humidification system
- Steam generation for kitchen service
- Temperature controls
- Removal of existing unused equipment
- Asbestos removal

4.2.5 System Optimization and Detailed Design

Based on the above steps, a decision can be made to proceed with detailed design and construction documents. The detailed conversion design should optimize the system to serve the building cost-effectively without sacrificing occupant comfort. System efficiency, equipment service life and maintenance requirements should be considered.

---

(1) Tierney and Fishman, "Real World Boiler Efficiency," presented at the 78th Annual International District Heating and Cooling Association Conference, June 1987, and "Real World Boiler Efficiency Update," presented at the 79th Annual International District Heating and Cooling Association Conference, June 1988.

Selection of the heating elements in the air handling units is critical for ensuring a large temperature drop, low air pressure drop and low water flow within the design limitations. In preparation of the documents, engineers should make sure that existing equipment and piping is isolated from new equipment for proper testing and cleaning.

4.2.6 Construction Schedule

When a building is being renovated for new occupancy, the construction schedule is generally easy to formulate. However, a more complex construction schedule is required for a building that will be occupied during the heating system conversion. Residential high-rises, hotels, and industrial plants with process loads require precise construction schedules.

Planning, construction documents and bidding for an occupied building should be in place about three months before actual construction begins. The schedule will depend on the size and complexity of the project.

4.2.7 Testing and Commissioning

Proper testing, balancing, and adjustment are imperative for energy efficiency. Equipment should be tested to determine if it meets the design specifications. Testing, balancing, and adjustment with central calibration should be implemented by experienced and qualified personnel. The organization that will test and calibrate the equipment should be independent from the installation contractor and should preferably be hired directly by the building owner.

Many systems function differently on a seasonal basis, so testing and balancing should be performed at several different times of the year. Balancing of the air handling and radiation equipment should be coordinated.

When new hot water heating coils are installed in existing air handling units, air pressure drop is higher with multi-row coils than with a single-row steam coil. Therefore, fan adjustments are necessary to deliver the proper air volume and temperature.

It is important to install adequate taps in piping at each heating coil for inserting pressure and temperature sensors for balancing the hydronic system. Proper balancing is extremely important for energy conservation as well as to ensure comfort and minimize operating costs.

Freeze protection systems must be tested if they have been installed in air handling systems. Testing should also be done to ensure that: air is mixing properly to eliminate air stratification at the coil inlet; fresh air inlet dampers close tightly upon fan shutdown; and blades are gasketed for minimal air leakage.

4.3 Steam Systems

4.3.1 Steam Distribution

General Considerations - Existing piping can often be converted from steam to water, but the system design must be checked thoroughly to determine:

- how steam is distributed,
- how condensate pipes are connected,
- if pipes are in good condition and can withstand the required static pressure, and
- if pipes are large enough and are properly circuited.

If steam pipes are over-sized they often can be re-used, generally as the hot water return circuit, because less heat will be lost from the pipes due to the lower return temperature.

Because air rises to the high points in the system and will obstruct water circulation, all high points must have air vents. Normally in steam piping, automatic air vents are installed on radiators and at the end of the steam main. These vents cannot be used in a hot water system, and must be replaced with manual air vents designed specifically for hot water.

One-Pipe Systems - Buildings with one-pipe steam systems are often badly corroded and are difficult and costly to convert. In most cases, these systems are entirely replaced. However, if the existing distribution system is usable, the system can be converted by replacing the air vents and adding return circuits, expansion tank, distribution pump and make-up water connection.

There are many variations, but most one-pipe systems have the basic characteristics shown in Figure 4.1. Figure 4.2 shows this system converted to use district hot water. Conversion of cast iron radiators, which are generally used in one-pipe systems, is discussed in Section 4.3.3.

Two-Pipe Systems - Condensate pipes are normally smaller than steam pipes, and are often badly corroded, so these pipes may have to be replaced. Factors to consider regarding sizing include the performance of existing and new terminal equipment and the temperature drop requirements of the district heating system.

When converting to hot water, steam traps must be removed or disabled because they will obstruct water flow. A thermostatic trap can be disabled by removing the bellows so that the body of the trap acts as an outlet flow orifice. If these units remain in the system (without being disabled), they can leak and can cause increased pressure drop.

Typical hydronic system elements must also be added, such as an expansion tank, make-up water connection and circulating pump(s). Pumps are discussed in detail in Section 3.4.2.

Figure 4.3 shows a basic two-pipe, low-pressure steam distribution system with gravity return. Figure 4.4 shows a typical high-pressure installation. There are more variations in two-pipe systems than one-pipe systems; however, most have these fundamental features. Figures 4.5 and 4.6 show these same basic two-pipe systems converted to use district hot water.

Pipe Insulation - Heat loss through pipe insulation is considerably lower in hot water systems because of the lower temperatures used. In steam systems, temperatures are around 215°F (102°C), whereas the average water temperatures during 80% of the heating season are generally 140°F-150°F (60°C-66°C) in the supply pipe and 120°F-130°F (49°C-54°C) in the return. All existing pipes to be re-used with hot water should be insulated to reduce heat losses in order to direct the heat to areas needing heat. It is

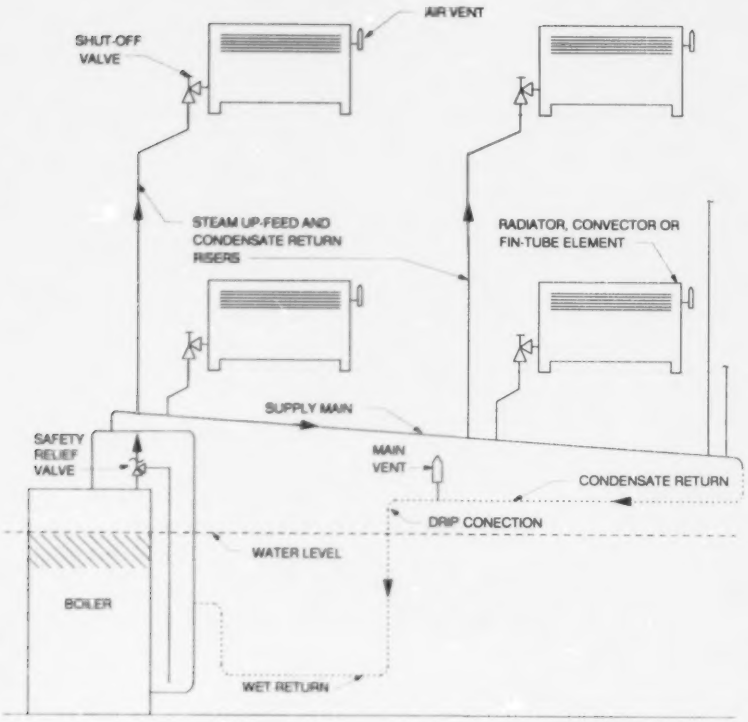


Figure 4.1: Basic one-pipe steam heating system

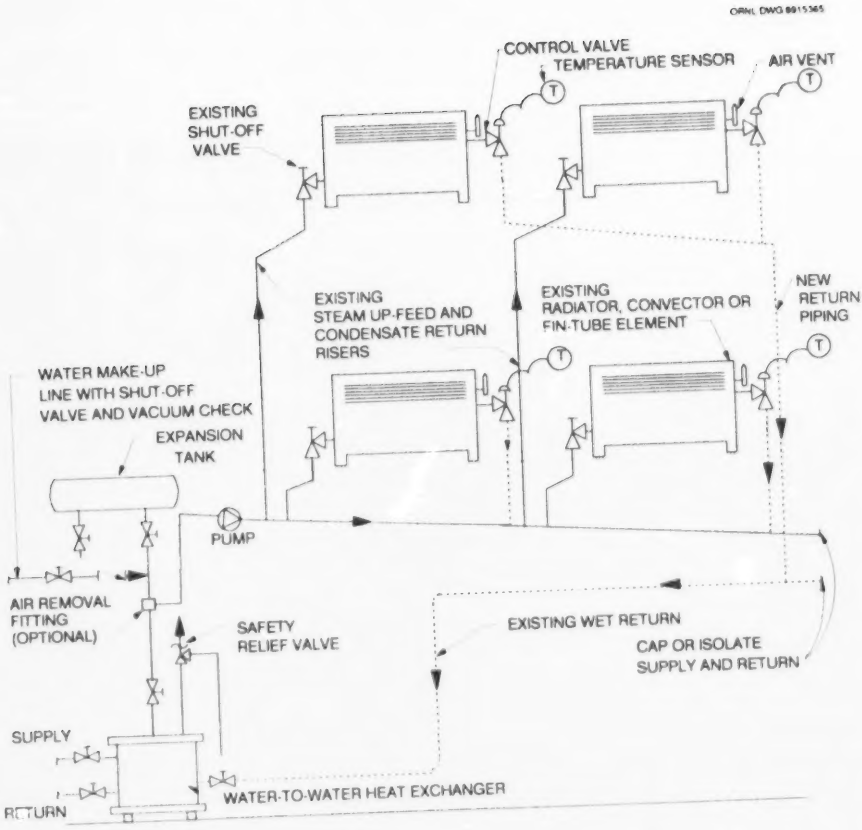


Figure 4.2: One-pipe steam heating system modified for hot water district heating

safest to insulate and cover all pipes located in occupied areas.

Hard-to-Heat Areas - In some buildings it has previously been necessary to increase the discharge air temperature or the steam pressure in order to adequately serve hard-to-heat areas. The reasons these areas are hard to heat should be pinpointed, and may include leaky windows with excess air infiltration, lack of proper air distribution, lack of adequate heat transfer equipment, plugged-up piping distribution and/or bad controls on space heating equipment. These are examples, but the important point is to isolate and remedy the problems because this is the least expensive method of operating the mechanical system at its maximum efficiency.

4.3.2 Heat Exchangers

Efficiency decreases considerably when existing shell and tube (S&T) heat exchangers are converted from steam-to-water to water-to-water operation because baffle spacing is designed differently for these two applications. Also, it is more costly to convert straight-tube or U-tube S&T heat exchangers from steam to hot water than to purchase new units because it will require supplementary heat exchangers to obtain the required heat output. Therefore, replacement of these types of S&T steam-to-water heat exchangers is recommended.

Large capacity gasketed plate heat exchangers can be readily converted by adding more plates to provide additional capacity. This will require new gaskets. Welded or brazed plate heat exchangers do not have removable plates and therefore can't be modified. Welded or brazed units are available in capacities up to about 2.5 MBtu/hour (700 kw each), and cost less than units with replaceable gaskets and plates. There is no need for gaskets in these units because they are totally welded.

Types of heat exchangers, and their advantages and disadvantages, are further discussed in Section 3.2.1 and Section 5.2.

4.3.3 Radiation

Radiators and Convectors - Steam radiators may be converted to hot water if they can withstand the required static pressure and will have adequate heating capacity with hot water. Normally, pressure will not be a problem. However, multi-story buildings or direct connection to a district heating system could over-pressure some radiators.

A steam radiator or convector radiates less heat when hot water is used because of the lower media temperature. However, old radiators are often over-sized due to over-estimation of building heat loss as well as safety factors used in equipment sizing. Therefore, in many cases, existing radiators may be adequate.

Column cast iron radiators fitted with only bottom nipple connections between sections must be replaced when the system is converted to hot water.

Radiators with sections that are connected on the top and bottom may be converted to hot water. Convector heating elements are normally composed of copper tubing with aluminum plate fins, and also can be supplied with hot water. When converting a steam radiator or convector, existing supply valving can be re-used unless it leaks or otherwise does not operate properly.

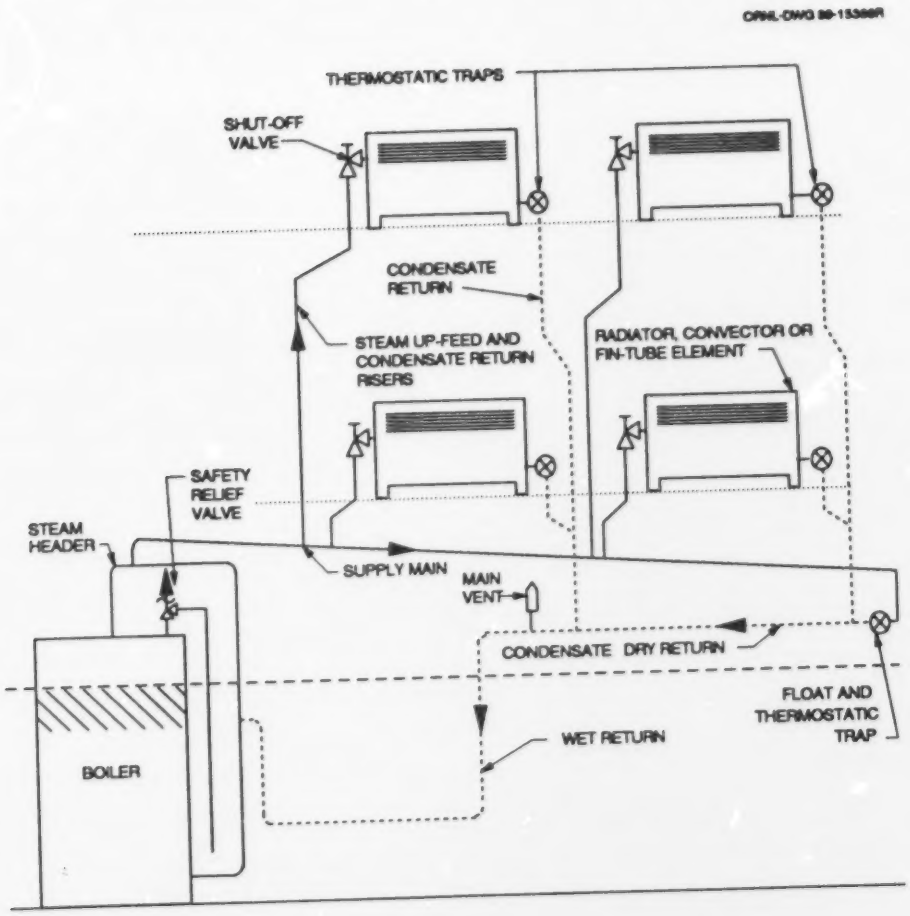


Figure 4.3: Typical two-pipe steam heating system (gravity return)

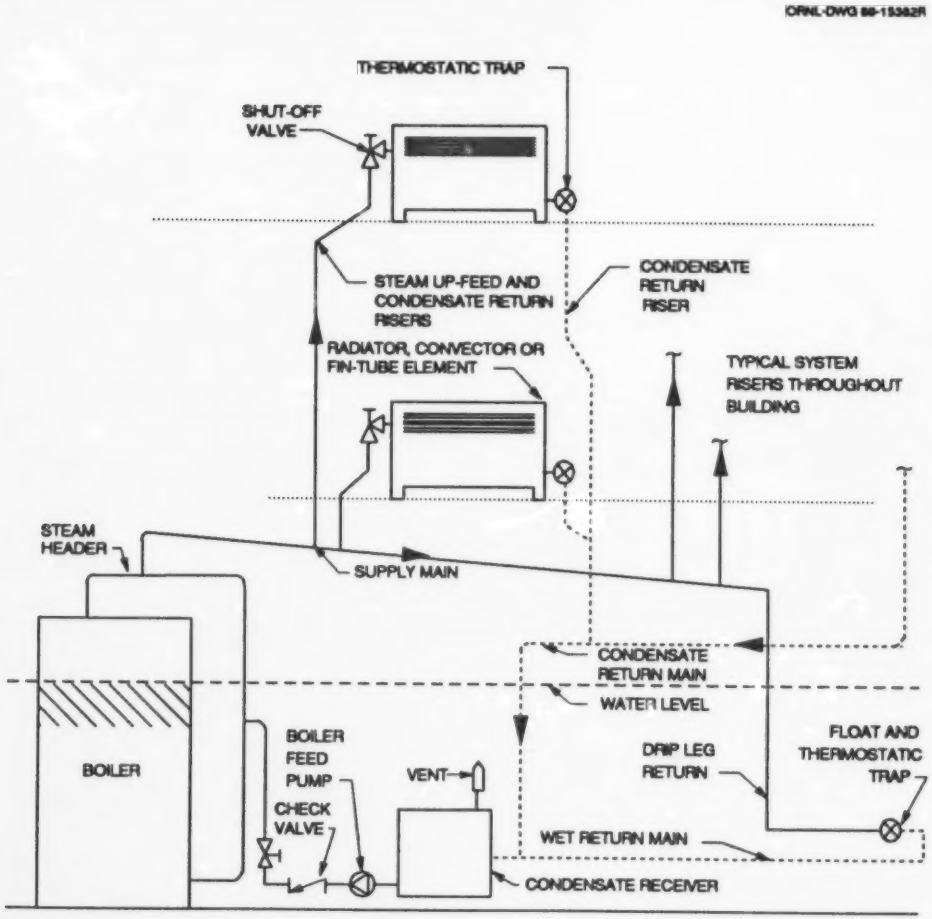


Figure 4.4: Typical two-pipe steam heating system, gravity return with boiler pump and receiver set (high-pressure system)

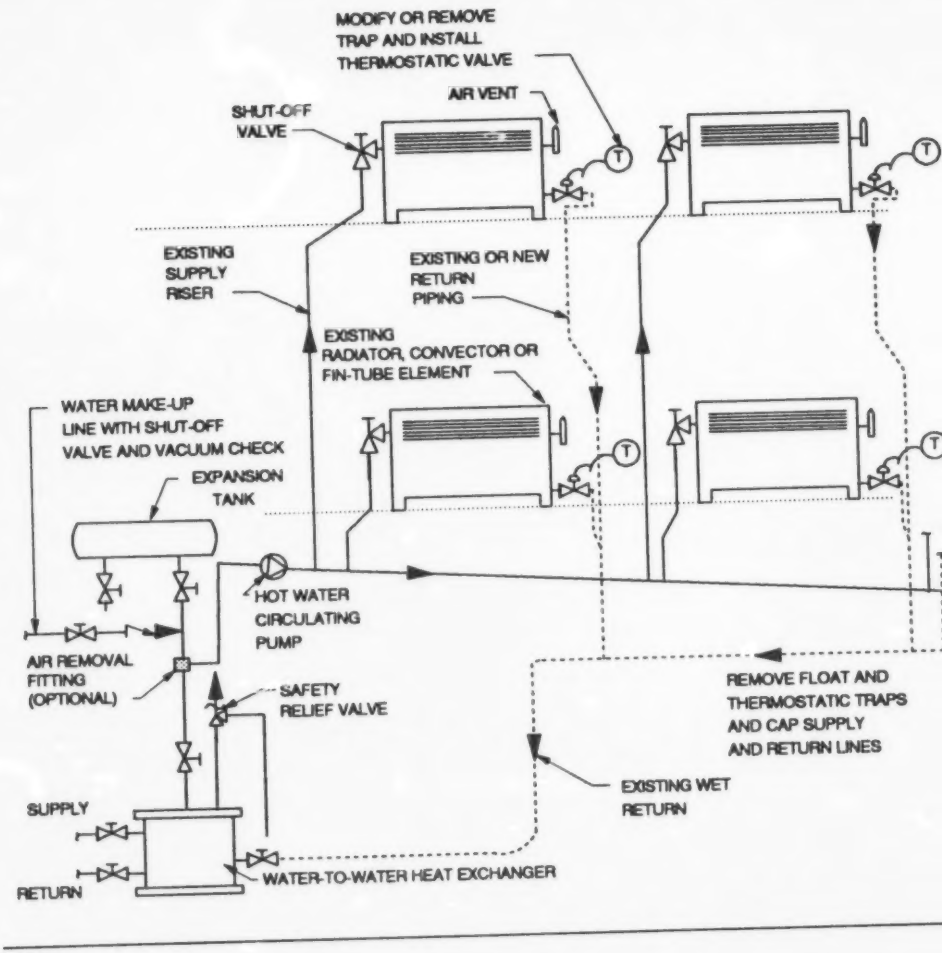


Figure 4.5: Two-pipe steam system modified for hot water district heating

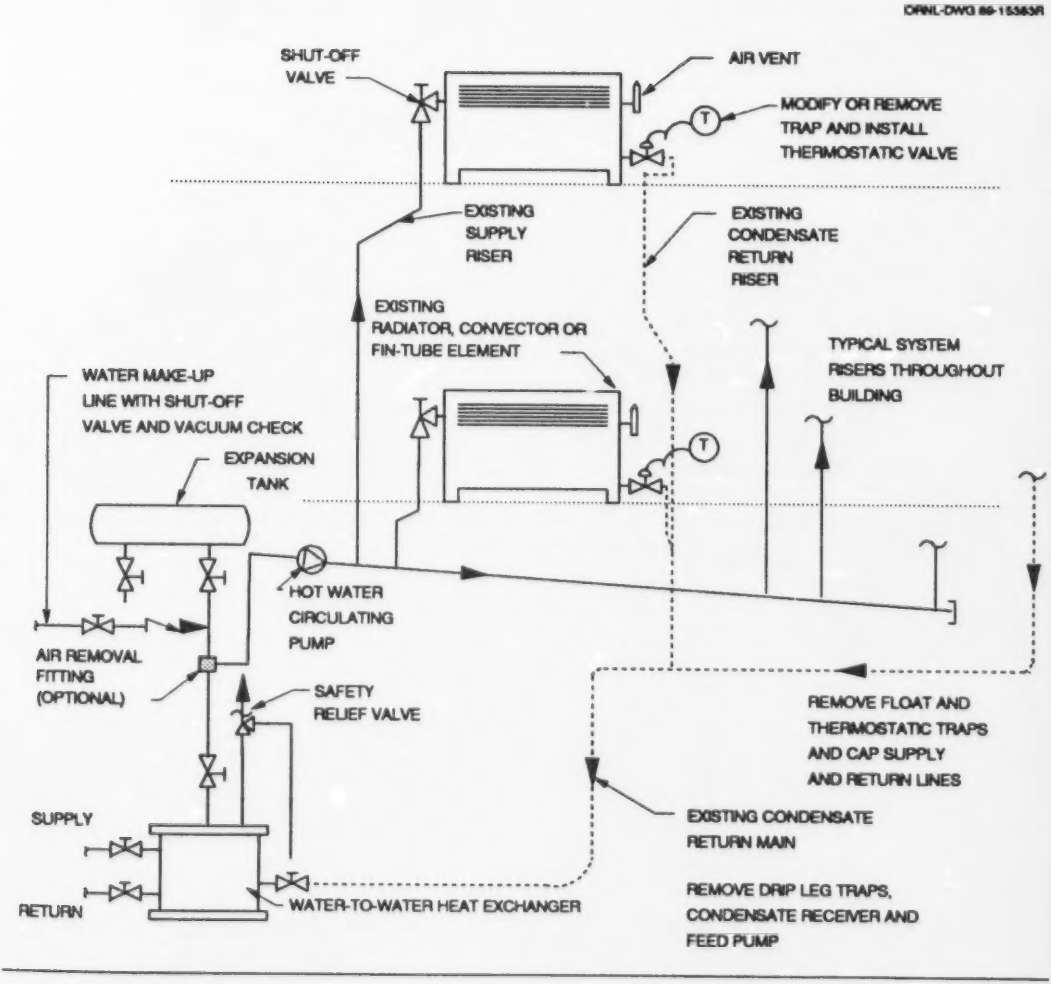

ORNL-DWG 89-15565R
SHUT-OFF VALVE
AIR VENT
MODIFY OR REMOVE TRAP AND INSTALL THERMOSTATIC VALVE
EXISTING SUPPLY RISER
EXISTING CONDENSATE RETURN RISER
EXISTING RADIATOR, CONVECTOR OR FIN-TUBE ELEMENT
TYPICAL SYSTEM RISERS THROUGHOUT BUILDING
WATER MAKE-UP LINE WITH SHUT-OFF VALVE AND VACUUM CHECK
EXPANSION TANK
HOT WATER CIRCULATING PUMP
AIR REMOVAL FITTING (OPTIONAL)
SAFETY RELIEF VALVE
REMOVE FLOAT AND THERMOSTATIC TRAPS AND CAP SUPPLY AND RETURN LINES
SUPPLY
RETURN
WATER-TO-WATER HEAT EXCHANGER
EXISTING CONDENSATE RETURN MAIN
REMOVE DRIP LEG TRAPS, CONDENSATE RECEIVER AND FEED PUMP

Figure 4.6: Two-pipe steam system (high pressure) modified for hot water district heating

Depending on the control system chosen, thermostatic valves may be added to provide individual control. Non-electric thermostatic control valves have design limitations that should be observed.

The thermostatic trap present on radiators connected to two-pipe steam systems can be disabled by removing the internal components. The disabled trap will act as a balancing element. It is normally not necessary to remove the trap itself. The existing air vents should be removed and plugged. A new manual air vent designed for hot water should be installed at the high point of the radiator.

For radiators connected to one-pipe systems, a new return line should be installed. This should be connected at the opposite end of the radiator from the supply line and at the opposite elevation from the supply line. In two-pipe systems, if the existing condensate lines are in good condition and are large enough, they can be re-used for hot water return.

Figure 4.7-a and 4.7-b illustrate typical radiator modifications for one-pipe and two-pipe systems, respectively.

The distribution system for the radiators must have a separate control for resetting the supply water temperature in relation to the outdoor air temperature. The reset schedule is used on the radiator sub-system only when multiple subsystems are on the same heat exchanger.

When existing radiators are re-used, the water temperature drop through these radiators is small due to the small surface area. When the temperature drop is low, the water flow is larger. Therefore, the distribution system should be checked for proper capacity.

In buildings over four stories, the steam radiator inlet and outlet unions are weak points. These unions are generally rated for a low operating pressure, and do not hold well under hydrostatic test pressure. As a result, they are not sufficiently reliable to operate at more than about 30 psig (207 kPa).

Fin-Tube and Baseboard Convectors - Conversion of fin-tube and baseboard convectors requires minimal modifications, similar to those for radiators. A new air vent designed for hot water should be installed, and thermostatic traps must be modified or removed.

It is important to check the space heat loss where these types of units are installed. These units are generally sized based on 215°F (102°C) steam inlet temperature. After conversion to hot water with an inlet water temperature of 180°F (82°C), the heat output is only 70% of the original design. If more capacity is necessary, additional heating elements must be added to satisfy the load. Sometimes this is unnecessary because energy conservation has reduced the heating requirements.

If the space is served by ventilation equipment, additional heating can be furnished by higher air temperatures in the air handling system.

4.3.4 Air Handling Systems

Heating Coils in Air Handling Units - Many older installations are two-pipe systems with steam supplied to coils in the air handling units. Usually, the coils are operated on 15 psig (103 kPa) low pressure steam service or high pressure steam. Sometimes records

ORNL-DWG 89-15388R

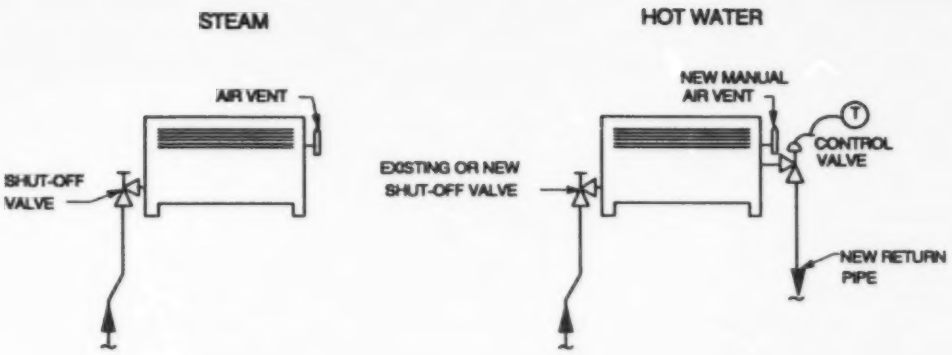


Figure 4.7a: Typical conversion of one-pipe steam radiator

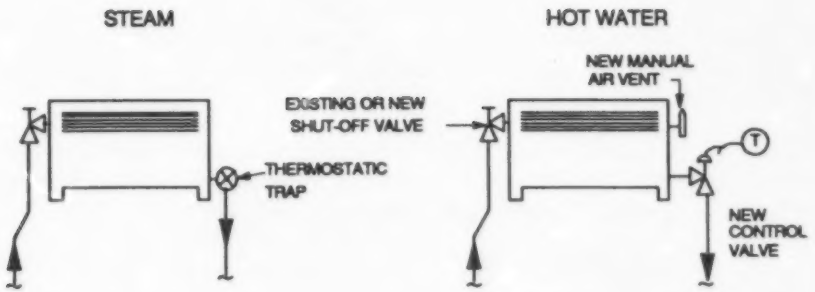


Figure 4.7b: Typical conversion of two-pipe steam radiator, convector or fin-tube element

on coil test pressure are lacking. Coils should be pressure tested to determine if they can withstand the required static pressure, especially for buildings over four stories. If possible, the coil manufacturer should be consulted to verify the possibility of coil conversion.

In general, coils have lower heating capacity when used with hot water. Actual heat demands must be calculated and compared with the expected heat output from the heater after conversion. If the existing coils are too small, new coils should be installed.

In older buildings some steam coils might be designed to take 100% outside air. If so, the coils should have adequate heating surface and could be used with a new mixed air temperature and lower media temperature, provided that 100% outside air is no longer required. However, in colder climates it is important to install freeze protection, as discussed below.

Certain types of coils, such as steam distributing coils (which have internal pipe distribution with nozzles, and feeders with baffles), will have a very low temperature drop and high pressure drop. These coils are not appropriate for hot water.

When converting a steam coil to hot water, steam traps must be removed and an air vent must be installed (see Figure 4.8). It is least costly to retain the supply line in the existing location. However, if the coil is exposed to fresh air, the supply line should be changed, if necessary, so that the hottest water is located where the air is coldest.

Coils exposed to potential freezing must have adequate freeze protection, including a circulating pump and a freeze protection thermostat (see Figure 4.9). Design conditions presenting potential freeze-up concerns vary depending on climate. In the Minnesota climate, for example, this is a concern with more than 25% outside air. A low temperature air sensor thermostat located on the leaving side of the coil, set for 40°F (4°C) will shut off the fan motor to protect the coil from freeze-up.

When a building in a colder climate has many air handling units, and some of the air handlers are pulling large amounts of outside air, a glycol/water heating loop should be considered. Freeze protection measures as noted above will be required to avoid the possibility of freezing the glycol/water heat exchanger.

Control systems can often be kept in their original configuration, but control valves may have to be changed and it may be advantageous to upgrade control systems for additional energy conservation, as discussed in Section 4.7.

Figure 4.10 shows the recommended control design for coils. Figure 4.11 illustrates alternative designs which will function and may be most cost-effective in some situations, but will generally provide a lower temperature difference.

Some steam coils have double controls: a temperature-controlled steam valve and a face and bypass damper. When converted to hot water, the bypass control sequence should be deleted and the bypass on the air side should be closed. The entire air flow should pass through the coil with minimum air bypass. This will reduce the return water temperature to the district heating system, and will reduce the possibility of coil freeze-up due to cold air stratification and low water flow. Steam coils with face and bypass dampers, as described above, are often installed as preheat coils, or in other lines where there is

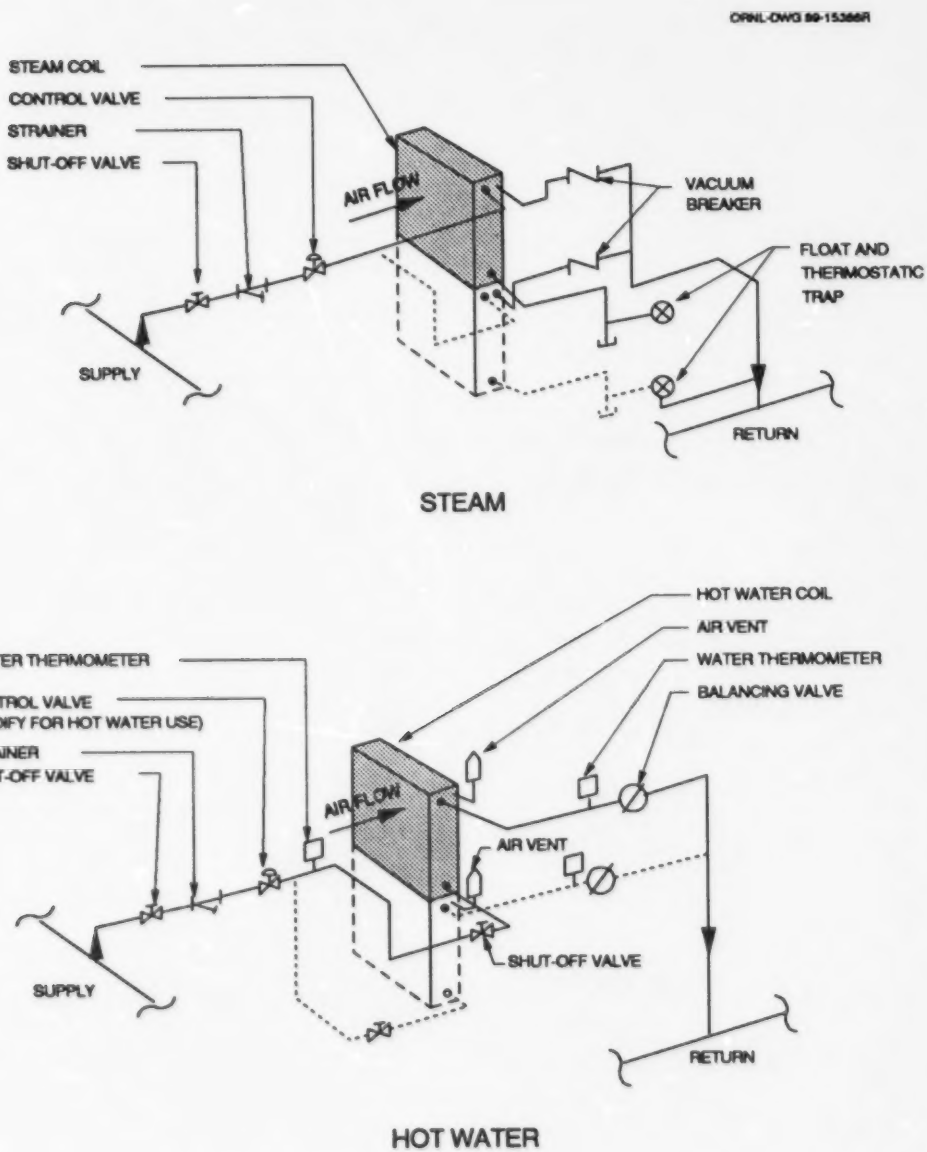


Figure 4.8: Typical air-heater conversion

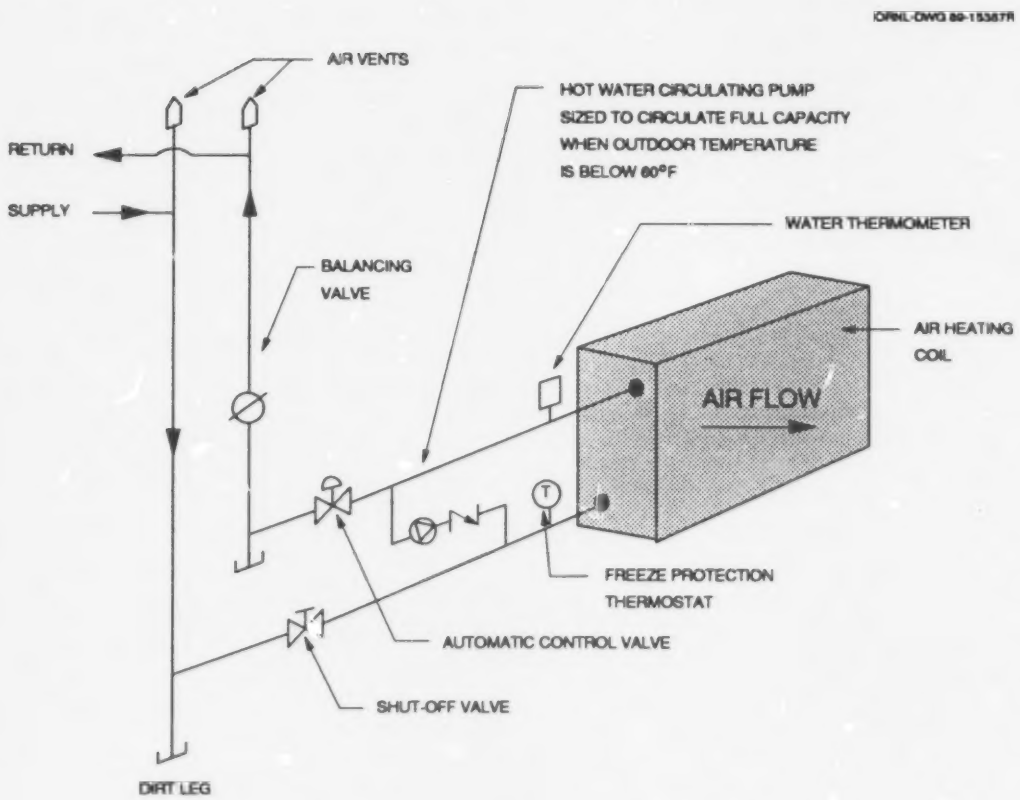


Figure 4.9: Typical air heating coil water connection with circulating pump for freeze protection

ORNL-DWG 89-15388R

- 2-WAY ON-OFF THERMOSTATIC CONTROL VALVE
- INTERMITTANT DISTRICT FLOW ONLY
- CONSTANT FAN-ON CYCLE HEAT
- LEAST COST

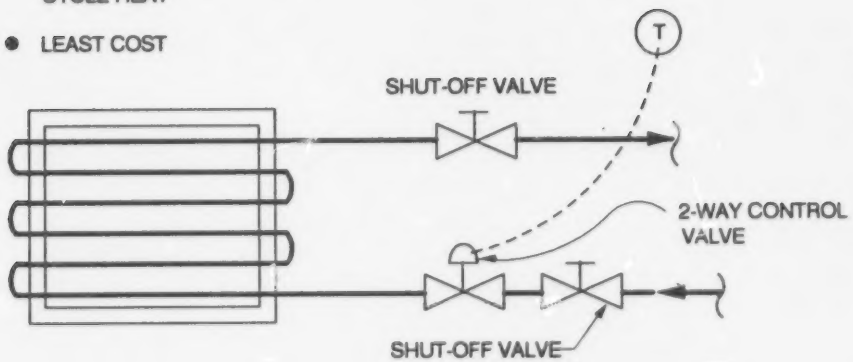


Figure 4.10: Recommended coil control design

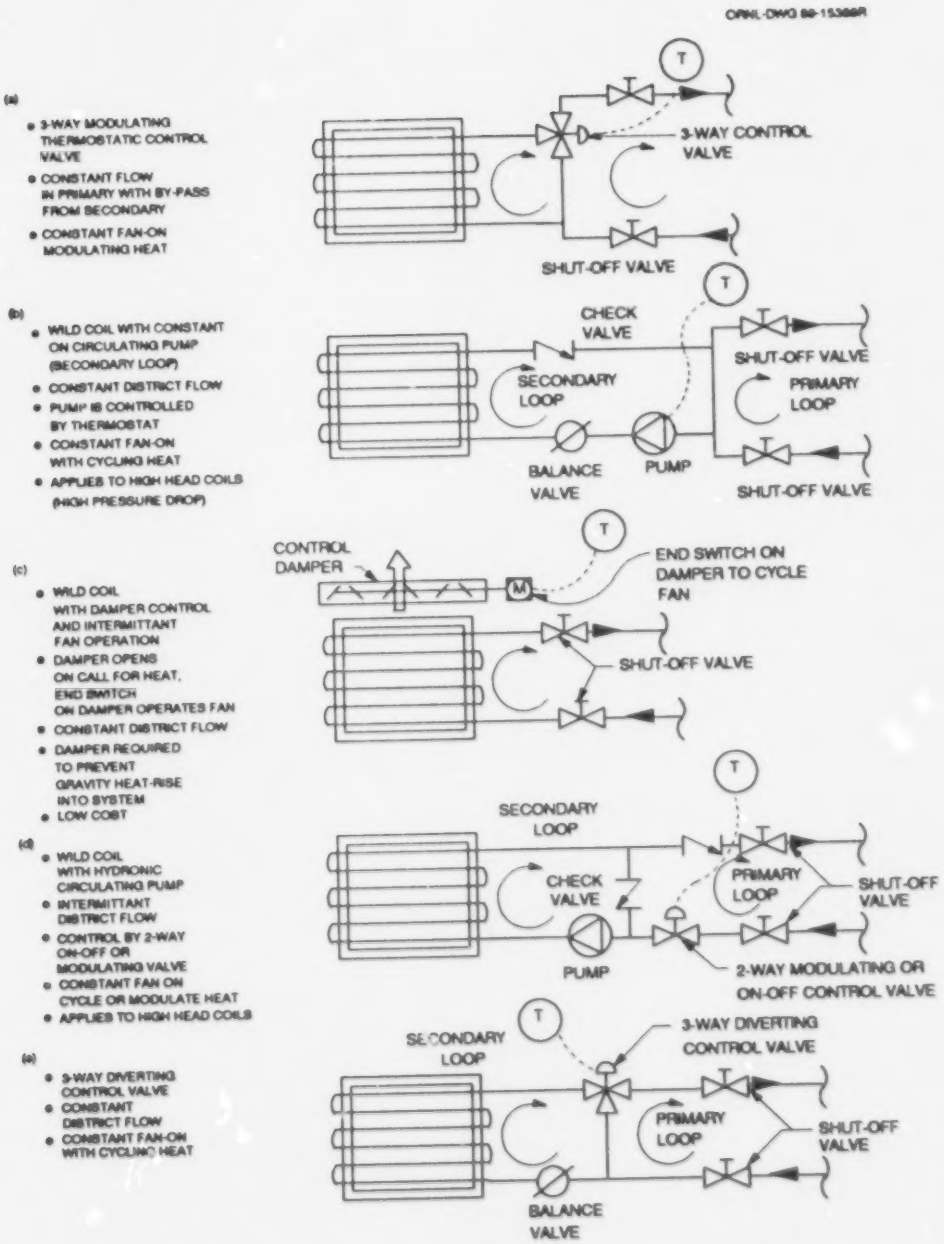


Figure 4.11: Alternative coil control designs

the risk of freezing. It is recommended that such coils be piped into a glycol system and/or the coil control system be designed to minimize the risk of freezing, as shown, for example in Figure 4.9.

If the system operates with recirculated air, the minimum outside air flow should be checked to determine if it is consistent with current standards. However, under many energy codes, the requirement for ventilation can be reduced.

With conversion to hot water district heating, existing air heaters can often be modified to be consistent with current standards. The fresh air inlet dampers can be upgraded to minimize air leakage and maximize use of recirculated air.

Reheat and Booster Coils in Duct Systems - In the 1950s and 1960s it was very common to have buildings with central air handling units and reheat coils (for air reheating after a cooling coil) or booster coils (for individual room temperature control) for each space. These coils are generally made of 1/2 inch (13 mm) copper tubes with continuous aluminum fins, and are designed to slide into the ductwork or are flanged for bolting to flanged ductwork.

Coils with plain tubes can be converted for hot water district heating. The output rating does not vary much, because the coil, in general, is selected to raise the discharge air temperature between 5°F and 15°F (3°C and 8°C). The water pressure drop will be a little higher than the normally selected hot water coils. The coil heating capacity will have to be verified to match the space heating load, since the unit was probably sized for an average of 2 psig (14 kPa) steam and is being considered for a hot water supply temperature of less than 200°F (93°C).

Fan-Coil Units - Convectors provided with self-contained fans are called fan-coil units. These units can use recirculated room air or be supplied with air from a remote point. The unit usually contains a one-row steam coil and sometimes a chilled water coil or direct expansion refrigerant coil.

The heating coil in fan-coil units may be used with steam or hot water. The conversion from steam to hot water is simple, requiring only modifications to the coil piping connection on the return side and modification or replacement of the steam trap, as discussed previously.

A unit with a chilled water coil may be converted to hot water by completely eliminating the steam coil and using the cooling coil in the heating mode. Since the unit will provide both heating and cooling, two pipe systems and a changeover control valve at the heat exchanger will be required, as described below under "Cooling Coils Used for Heating in Winter." The control valve on the coil will require sequence modifications to operate in the heating mode. Another option is to install a smaller heating control valve, with the existing cooling control valve operating in the cooling mode.

Unit Heaters - Unit heaters are factory-assembled and consist of a heat exchanger (steam, hot water, gas, or electricity), fan, motor and casing. Unit heaters with axial fans are usually installed in manufacturing areas, warehouses or shops, while units with centrifugal fans are generally used in building entrances, stairways, factory offices and loft spaces.

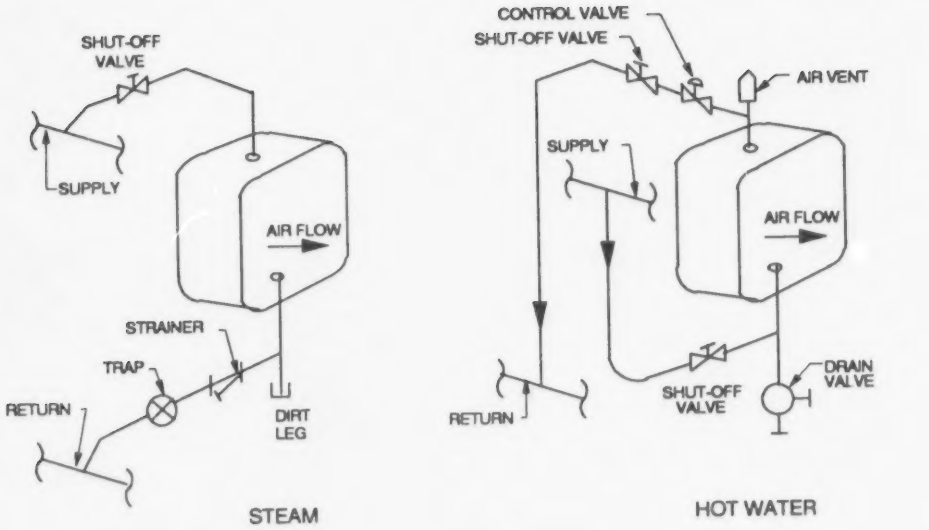


Figure 4.12: Horizontal unit heater

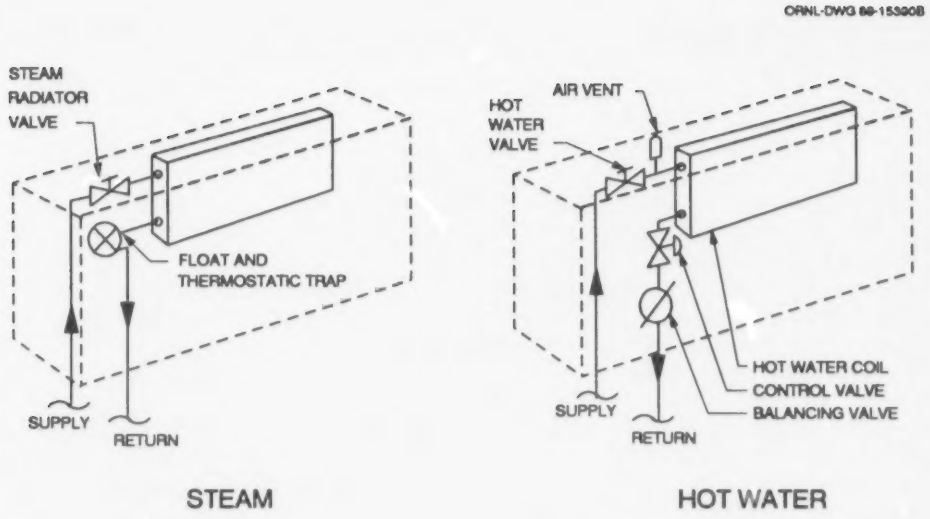


Figure 4.13: Cabinet unit heater

Steam unit heaters can be converted to hot water with minimal piping modifications (see Figures 4.12 and 4.13). The extent to which output capacity is reduced will depend on the hot water supply temperature.

Unit heaters are usually controlled by a room thermostat that switches the fan on and off. Sometimes a pneumatic or electric control valve will control the steam flow in response to the thermostat. Automatic temperature control valves should be added to unit heaters to reduce the return water temperature. At the least, an automatic shut-off valve (usually a solenoid valve connected to the fan switch or contactor) should be installed to prevent water circulation when the fan is off. This will prevent high return water temperatures.

Cooling Coils Used for Heating in Winter - In buildings with central air handling units and chilled water distribution for cooling, the cooling coils may be used for heating. This helps to reduce conversion costs by avoiding coil replacement. Fan operating costs can also be reduced, due to reduced air resistance achieved by elimination of separate heating coils. Cooling coils can be used for heating as long as cooling is not required during the heating season.

Chilled water cooling coils are very good candidates for conversion to hot water heating for the following reasons:

- Most buildings with one central air handling unit per floor or area have an economizer cycle in the control sequence, and the air handler is designed to handle more than the minimum required fresh air. During warm days in between heating and cooling seasons the building can be cooled by introducing additional outside air, so the chilled water coil will not be needed for cooling. This will eliminate switching from heating to mechanical cooling on a daily basis.

- Since a large heat transfer surface is available in cooling coils, the hot water temperature entering the coils can be lower. This helps ensure a low return water temperature to the district heating system.

- It is possible to use mainly primary return water to satisfy the building heating needs.

The existing chilled water distribution may be converted to dual water temperature using the chilled water pumps. It will require the installation of a heat exchanger and three-way diverting valves on both the supply and return piping on the chiller. The valves can be pneumatic or electric, and be controlled by a heating-cooling switch at the main control panel. The control sequence should have a time delay so that valves to the chiller do not open unless the water temperature in the piping circuit is below 75°F (24°C).

Another option is available if a new heating distribution system is being considered. The cooling loop can remain as is, and the new heating pipes can serve the existing cooling coil when the system is in the heating mode. New hot water connections to the chilled water piping and a new control valve to match the heating load are required. In the cooling mode the control sequence on the air handler will remain the same and the heating control valve will be closed. In the heating mode the chilled water control valve will be closed.

If the existing cooling coils have three-way modulating valves, the system can be used as is, provided the space temperature does not require close tolerance. This situation will require a very small investment for conversion. The valve is sized for a large water flow to meet cooling needs. In the heating mode the valve should close and hot water must bypass the coil because the coil does not require a large flow for heating. Therefore, the space temperature might overheat if the valve does not close enough.

A booster pump on the coil should definitely be installed to assure full water flow in the coil and to avoid coil freeze-up on units with fresh air intake.

When intending to use cooling coils with hot water, consideration should be given to:

- adequate pipe expansion joints,
- heat output requirements,
- water flow from heating circuits,
- water velocity required for proper heat transfer,
- adequate temperature control, including quality of valves,
- potential problems in switching between heating and cooling, and
- adequate pipe insulation to reduce heat losses.
- freeze protection.

Case History 3 in the Appendix describes an example of the use of cooling coils for hot water heating.

4.4 Hot Water Systems

4.4.1 Hot Water Distribution

The majority of hot water heating systems in use today are in the following categories:

1. Gravity hot water: Hot water is circulated by natural convection.

2. Forced hot water: A closed hot water system with a pump used to provide circulation. There are several types of forced systems.

   - Direct return: A circulation system routing water back to the primary heat exchanger via the shortest path from each appliance.

   - Reverse return: A circulation system using a return piping path from each appliance such that all circuits are of equal pipe length, i.e., self balancing.

   - Series loop or "mono-flow": A one-pipe system where all heated water flows through each consecutive heating element and then directly back to the source.

Gravity hot water systems are not easily adapted for district heating without conversion to forced operation. This conversion is common practice and is not covered in these guidelines.

Conventional forced hot water systems can use district heating with few changes. However, such systems should be evaluated for suitable temperature drop.

Many buildings with hot water systems were designed for constant flow, with constant temperature or temperature reset from an outdoor controller. Constant flow systems commonly have a three-way control valve so that the hot water supply will bypass into the return when the thermostat is satisfied. To meet the return temperature requirements in a district heating system, this bypass should be removed and the heating system converted to a variable flow system, as discussed in Section 3.4.2. In large buildings, not all control valves will close at the same time to generate a dead head in the hot water heating pump. By eliminating the bypass on three-way valves for over 95% of the control valves, the pump will ride its own curve without a need for replacement with an actual variable speed pump.

Such a conversion, which will reduce electrical energy usage, can usually be done by plugging the bypass line on three-way valves. However, valve size and characteristics must be checked for proper pressure drop and its impact on the present system design. Installation of two-way valves is usually the best solution.

4.4.2 Radiation

Normally, existing hot water radiation of any type is compatible with hot water district heating. However, temperature requirements and sizing must be checked. Often, even when rated for a temperature higher than that to be used in the converted system, oversizing of the units ensures adequate performance.

Some types of equipment, such as hot water radiant panels, are designed for use with low water temperatures, up to about 130°F (54°C). This offers the opportunity to use return water, thereby helping reduce the temperature of the water returned to the district heating system.

4.4.3 Air Handling Systems

Again, temperature requirements must be checked, but normally there will be no problem in connecting hot water coils, hot water unit heaters and other existing hot water elements in the air handling systems. As noted above, if a heater is controlled by a three-way valve, the valve must be changed to a two-way, flow-through type by plugging the bypass line, or a new two-way valve should be installed. Valve size must be checked for adequate pressure drop compared to system design.

In cold climates, heaters exposed to outside air must have adequate freeze-up protection, including a circulating pump, a standby temperature detector, and a freeze protection thermostat, as described in Section 4.3.4.

4.4.4 Unitary Water-to-Air Heat Pumps

Unitary water-to-air heat pumps connected to a recirculating water loop are most commonly used in large office complexes with large interior spaces. The system provides decentralized, year-round heating and cooling by continuously circulating non-refrigerated water throughout the building.

The water temperature is maintained throughout the year in an approximate range between 65°F (18°C) and 95°F (35°C). At the low end of this range, additional heat is needed from a supplemental heat source such as a heat exchanger, electric boiler or fossil

fuel boiler. During the cooling season, heat is dissipated from the unit into the circulated loop and rejected to the outdoors through a cooling tower.

Retrofit of the system involves only the installation of a heat exchanger in lieu of, or parallel to, an existing heat source. Due to the low temperature operation of this system in comparison to other heating systems, such as radiators and air handling units with higher heating supply temperatures, the heat exchanger requirement is very small. In addition, a large temperature drop can be employed on the primary side of the heat exchanger.

4.5 Gas/Oil-Fired Systems

4.5.1 Warm Air Furnaces

There are two basic types of warm air furnaces: gravity (natural convection); and forced air. There are many different designs within these two basic types. Gravity furnaces are usually not suitable for conversion to district heating. Conversion requires a new air handler, although in some cases installation of a coil and fan is sufficient. Forced air furnaces can often be converted to district heating with few changes required.

Furnace Retrofit - Figure 4.14 is a typical modern forced warm air furnace (gas, oil, or electric). Although details vary with different manufacturers, most have these common features.

The following are assumed to be typical of conditions found in single-family, warm air, gas/oil-fired installations:

- Furnace is the vertical up-flow type.
- Fuel input about 100,000 Btu per hour.
- Efficiency approximately 75%.
- Squirrel cage blower, replaceable filter section.
- Ducted supply air and return air to respective plenums.
- Average warm air supply temperature of 115°F to 135°F(46°C to 57°C).
- Average air velocity in ducts is 300 feet (92 meters) per minute in winter and 500 feet (153 meters) per minute in summer (with mechanical cooling).
- Warm air operating limit control in supply air plenum.
- Warm air safety limit control in supply air plenum.
- Single zone heating thermostat with cooling sub-base.
- Fan to cycle with heat rise in supply air plenum (winter).
- Fan to cycle with cooling unit (summer).

The furnace should be reviewed for deterioration, rusting, corrosion and wear. If the furnace is in good condition and it appears that the fan, cabinet, drives, air conditioning coil and heat exchanger will last another 10 years, it should be considered for retrofitting.

Figure 4.15 depicts the same furnace with an added hot water coil. Hot water coils for addition to warm air furnaces can be sized conventionally. The existing fan and motor must have sufficient capacity to overcome the additional pressure drop caused by the addition of the hot water coil. In most instances this is not a problem. If the pressure drop is too great, it can be rectified by changing the fan motor.

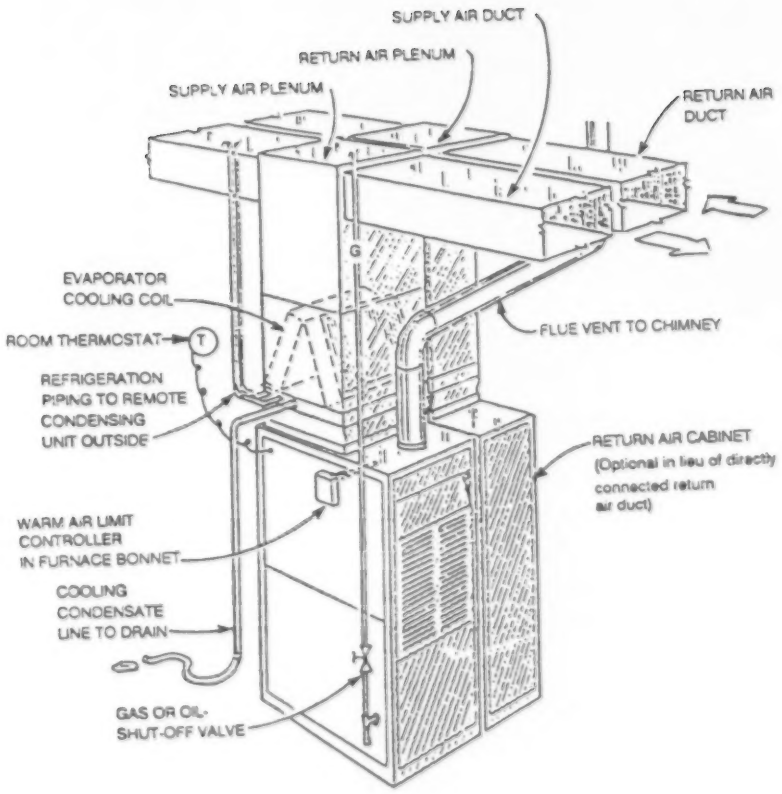

SUPPLY AIR DUCT
RETURN AIR PLENUM
SUPPLY AIR PLENUM
RETURN AIR DUCT
EVAPORATOR COOLING COIL
ROOM THERMOSTAT
T
REFRIGERATION PIPING TO REMOTE CONDENSING UNIT OUTSIDE
FLUE VENT TO CHIMNEY
RETURN AIR CABINET
(Optional in lieu of directly connected return air duct)
WARM AIR LIMIT CONTROLLER IN FURNACE BONNET
COOLING CONDENSATE LINE TO DRAIN
GAS OR OIL-SHUT-OFF VALVE

Figure 4.14: Typical warm air furnace (gas, oil or electric) with direct expansion cooling with remote refrigeration condensing unit outside

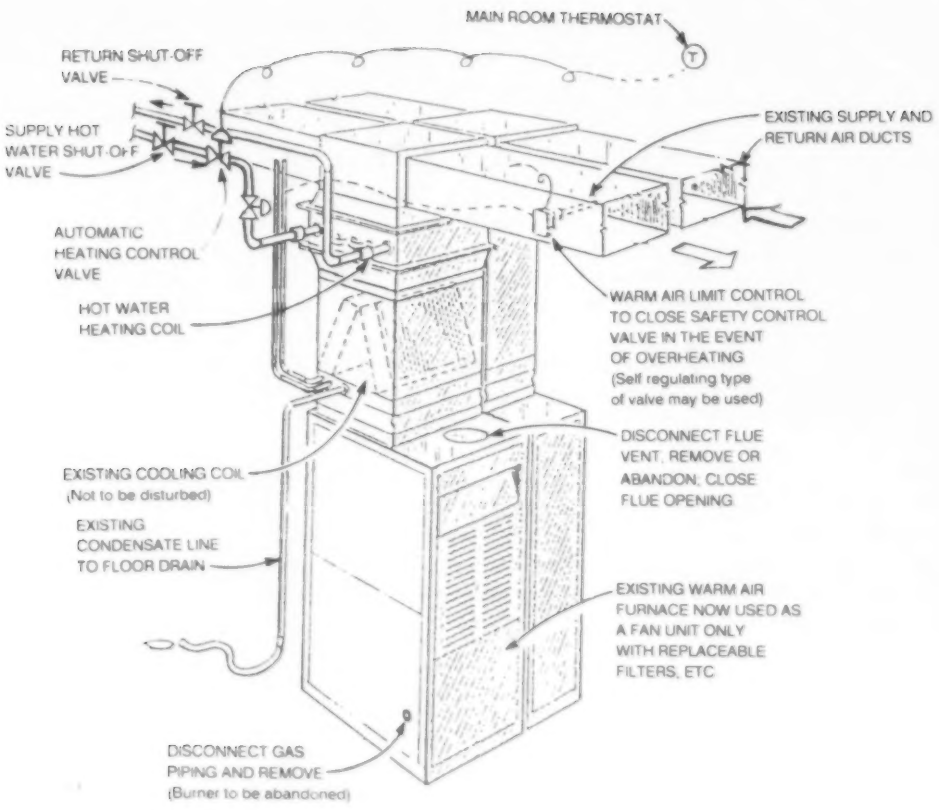

MAIN ROOM THERMOSTAT
T
RETURN SHUT-OFF VALVE
SUPPLY HOT WATER SHUT-OFF VALVE
EXISTING SUPPLY AND RETURN AIR DUCTS
AUTOMATIC HEATING CONTROL VALVE
HOT WATER HEATING COIL
WARM AIR LIMIT CONTROL TO CLOSE SAFETY CONTROL VALVE IN THE EVENT OF OVERHEATING (Self regulating type of valve may be used)
DISCONNECT FLUE VENT, REMOVE OR ABANDON; CLOSE FLUE OPENING
EXISTING COOLING COIL (Not to be disturbed)
EXISTING CONDENSATE LINE TO FLOOR DRAIN
EXISTING WARM AIR FURNACE NOW USED AS A FAN UNIT ONLY WITH REPLACEABLE FILTERS, ETC
DISCONNECT GAS PIPING AND REMOVE (Burner to be abandoned)

Figure 4.15: Warm-air furnace converted to hot water heating using hot water heating coil installed in supply air plenum.

Furnace Replacement - If the furnace must be replaced, the following options are available:

1. Replacement of the furnace with a fan-coil cabinet unit with hot water heating coil and direct expansion evaporator coil with a remote refrigeration condensing unit. These units are constructed as a total package at the factory, including heating coils, cooling coils, replaceable filters, fans, pre-charged refrigeration lines and controls. Most major manufacturers of heating and air conditioning equipment produce a variety of cabinet units for residential and commercial use.

2. Replacement of the furnace with a cabinet fan with add-on hot water heating coil. Due to space limitations where a packaged assembly may not fit, a built-up system may be achieved using a small box-fan and extending ductwork to a coil assembly.

3. Replacement of the furnace with a new furnace. This is generally a more expensive option.

Coil Selection - Hot water coils should be of serpentine configuration so that maximum heat extraction will take place. These types of coils are often used with solar heating systems, where entering water temperatures are relatively low and a high heat exchange efficiency is required to extract maximum heat.

Coils may be either two-row, three-row, or four-row, and should generally meet the following performance requirements:

- Heat output: 100,000 Btu per hour.
- Air temperature rise: 65°F (18°C) with entering air temperature of 70°F (21°C) and leaving air temperature of 135°F (57°C).
- Entering water temperature: 190°F (88°C).
- Leaving water temperature: 140°F (60°C).
- Water flow rate: 3.2 gallons (14.5 liters) per minute.
- Air volume: 1,500 cubic feet (139 cubic meters) per minute nominal.
- Static pressure drop through coil, air side: 0.25 inches (6.4 mm) water column maximum.
- Water pressure drop through coil: 0.4 feet (0.12 meters).
- Normal operating pressure: 125 psig (0.9 MPa).
- Maximum design operating pressure: 250 psig (1.7 MPa).

The above coil selection is based on district heating service from a substation serving multi-unit residential area. In such an arrangement, a 50-60°F (10-16°C) temperatu drop across the coils is realistic. Residential applications with fresh air, low air flow ar intermittent cycling will not be able to achieve a temperature drop exceeding this rang

Direct connection of residential warm air furnaces to district hot water, without a he exchanger, is also feasible. The major drawback is that the desired temperature drop district heating system (90°F or 32°C). Copper tubing coils should be able to exceed t 250 psig (1.7 MPa) working pressure. It is strongly suggested that a two-way safe control valve be added to shut off the district heating supply and return in case of prima control valve failure.

Coil Construction - The following sample specifications may be used in most resident

furnace retrofit applications:

- Tubes within the coil assembly shall be of seamless copper, 1/2 to 5/8 inch (13 to 16 mm) outer diameter. The tubes shall be expanded into full fin collars for a permanent fin-tube bond. Ends should be expanded into headers and soldered.

- Headers shall be of seamless copper with intruded tube holes to permit expansion and contraction without undue stress or strain. Entering and leaving water connections should be on the same side for easy access and connection.

- Fins should be of the plate type, aluminum or copper, with full fin collars for maximum tube-fin contact and uniform spacing.

- Casings shall be constructed of galvanized steel of reinforced configuration. They shall be flanged in such a manner to facilitate ease of mounting into existing duct systems modified with flanges to accommodate easy removal by unbolting, etc.

- Coils shall measure approximately 25 inch by 20 inch (64 cm by 51 cm) to accommodate typical residential duct systems.

Coil Testing - If coils are connected directly to the district system, the complete coil core assembly should be tested with approximately 315 psig (2.2 MPa) air pressure while immersed in warm water. The coil should be suitable for operation at 250 psig (1.7 MPa) working pressure. The coils should be certified as hydrostatically tested to the above pressures before shipment.

Coil Mounting and Transitions - An angle or "boot" type installation of coils in the supply air ductwork is recommended since it provides a gradual duct-to-coil transition with low pressure drop and less turbulence. A non-angle "slip-in" assembly would be satisfactory providing the duct-to-coil offsets do not exceed 15% of the width or depth dimensions. Sheetmetal connections should be made relatively airtight by taping or caulking with silicone.

Temperature Control and Trim - Experience has shown that the best control mode for common residential use is that illustrated in Figure 4.10: a simple two-way, on-off control valve which may be cycled upon demand for heat, independently or along with the fan. The alternative methods shown in Figure 4.11 will be functional but will provide a low temperature drop.

The system should be as simple and trouble-free as possible, with few accessories that require servicing or that could fail or leak. When water temperatures exceed 212°F (100°C) within piping systems, any leak or exposure would cause flashing, creating noise, steaming and probably damage to the system and surroundings. Therefore, all components must be rated for the conditions expected.

Shut-off valves facilitate shut-down for repairs, servicing and replacement of equipment. They should be reliable for 100% shut-off.

Use of ball-type shut-off valves, with Teflon seals and seats that will sustain temperatures and pressures specified by the district heating utility, is recommended. Control valves should also meet these design criteria and be operated by a solenoid or motor.

Seats should be the metallic, non-leaking type so that hot water erosion will not be a problem. It should be noted that very few control valves are known to meet these specifications. Among manufacturers which have produced such valves are Samson, Braukmann, Danfoss, Tour Andersson, and Stafa Controls. Common varieties of available zone valves have plastic or rubber seats and packing which will erode under the high pressure and temperature conditions found in district heating. Operators should be of a non-slamming variety to prevent water hammer shocking of the system.

Back-flow checks are a feature that would stop the district system return water from flowing back into the customer's area in the event of a breakage or leak. They operate in conjunction with the closing of the (normally closed) thermostatic control valve by the customer.

A safety shut-off control valve, such as a self-regulating thermostatic valve, can be installed as a limit control to override the primary valve and maintain plenum temperature in lieu of balancing.

4.5.2 Rooftop Units

Package air handling units, air make-up units, blow-through units or direct-fired units are used to heat make-up air in warehouses, shop areas, etc. They can be factory-assembled or site-assembled, and have a blower, heat exchanger, filter and fresh air and return air damper sections. They can have extensive ductwork for air distribution or they can be roof-mounted with air discharge directly into the room below or through a short duct. A typical rooftop unit is shown in Figure 4.16.

Package air handling units with gas or oil-fired heat exchangers can be converted to hot water heating, with no reduction in capacity, by installing a hot water coil in the ductwork and deactivating the heat exchanger, as illustrated in Figure 4.17. Blow-through units, which use squirrel cage fans, are not acceptable for conversion and must be replaced.

When selecting the hot water heating coil, the air pressure drop should be minimized. Air handling units are normally selected with minimal air resistance. Coils with a large air pressure drop might require replacement of the motor pulleys and sheaves to handle the additional pressure drop.

As noted in Section 4.1, gas or oil units are generally poor candidates for conversion.

4.5.3 Radiant Heaters and Unit Heaters

Radiant or infrared heating units are self-contained direct heating devices which may be gas-fired, oil-fired or electric. These types of heaters are effective for spot heating. Radiant heaters cannot be modified and must be replaced with hydronic blast coils or unit heaters.

Gas unit heaters are factory-assembled and consist of a fan, motor, casings, and an interchanger to vent combustion products from the heated space. These units cannot be converted to hydronic heating. They must be replaced with a similar unit containing a hot water coil.

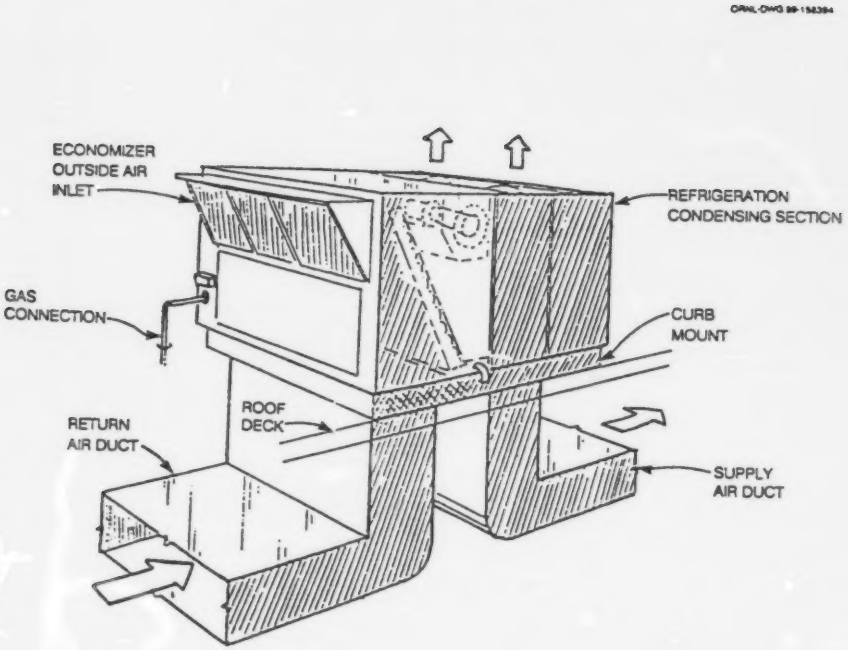


Figure 4.16: Typical rooftop unit

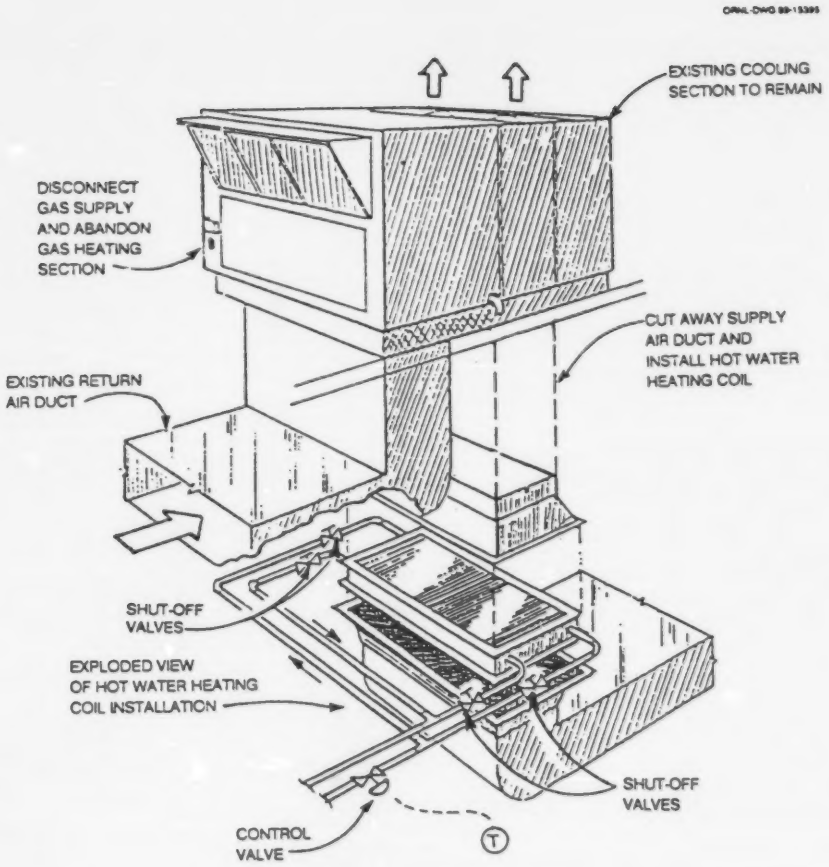

ORNL-DWG 89-15395
EXISTING COOLING SECTION TO REMAIN
DISCONNECT GAS SUPPLY AND ABANDON GAS HEATING SECTION
CUT AWAY SUPPLY AIR DUCT AND INSTALL HOT WATER HEATING COIL
EXISTING RETURN AIR DUCT
SHUT-OFF VALVES
EXPLODED VIEW OF HOT WATER HEATING COIL INSTALLATION
SHUT-OFF VALVES
CONTROL VALVE
T

Figure 4.17: Typical rooftop unit converted for hot water district heating

4.6 Electric Systems

4.6.1 Electric Resistance Furnaces

Conversion of electric furnaces is similar to conversion of gas/oil-fired furnaces as described in Section 4.5.1 and illustrated in Figures 4.14 and 4.15.

4.6.2 Rooftop Units and Air Handling Units

Conversion of electric rooftop units is similar to conversion of gas/oil units as described in Section 4.5.2 and illustrated in Figures 4.16 and 4.17. Electric resistance elements in air handling or fan-coil units must be replaced with hot water heating coils. An exception would be fan-coil units which are used for minimal heating requirements during the spring and fall; these units are generally retained unmodified.

4.6.3 Air-to-Air Heat Pumps

In these systems, an electric-driven refrigeration compressor is used to extract heat from outside air to provide warm air during the heating season, or to extract heat from the building space and discharge it to the outside air during the cooling season. Conversion requires installation of a hot water coil in the supply air unit.

4.6.4 Other Systems

Electric unit heaters, electric baseboard units and radiant panels cannot be converted and must be replaced with hydronic units.

4.7 Control Systems

4.7.1 Requirements For Conversion

The following control system additions and/or modifications should be made when converting to hot water district heating:

1. Install controllers for new heat exchangers.
2. Install controllers for new secondary system equipment.
3. Replace control valves or modify them for reuse.
4. Install freeze protection detectors and fan shut-down interlock for air handling units with hot water or glycol heating coils.
5. Change control sequence for converted steam-operated air handling units that are controlled with face and bypass damper (bypass must be deleted).
6. Install automatic shut-off valves on unit heaters and similar equipment.

No other changes in control systems are usually required, but it may be advantageous to upgrade systems for additional energy conservation, as described in the following section.

4.7.2 Upgrading Controls For Energy Efficiency

Old control systems are often less accurate than new systems and are hard to adjust for the most economical operation. The following changes will improve efficiency and

controllability:

Outside Air Damper - Dampers should be adjusted for the *minimum* required outside air flow consistent with building occupancy. Damper actuators should close tightly. It might be advantageous to install new low-leakage dampers, especially when 100% recirculated air is used during the night or for the morning warm-up cycle. A standard damper can allow from 5% to 30% leakage when closed. New low-leakage dampers provide better energy efficiency as well as improved temperature control.

Control Valves - A leaking valve is a major source of energy waste. Valves should be positively shut off when no heat is required. Unit heaters, cabinet units at entryways and similar air heaters with fan power may be controlled by starting and stopping the fan while coil water flow is running wild. It is necessary to install solenoid on-off valves or modulating control valves to reduce the return water temperature and conserve energy when the system is not in operation.

Temperature Sensors - Proper location of sensors in rooms is essential for achieving correct temperature measurement. Systems operating with a fixed temperature supply air should be fitted with a temperature sensor or mixed air controller in the return/exhaust air duct so that internal loads (lights, people, equipment, sun radiation, etc.) will reduce the temperature of the supply air in the heating mode.

Many ventilating systems with dual duct temperatures rely on fixed hot deck/cold deck temperatures, or reset the hot deck from the outdoor temperature, leaving the cold deck at a fixed temperature. These types of settings do not take actual zone loads into account and therefore waste energy. Energy can be saved by having the hot deck temperature controls respond to the space thermostat having the greatest heating demand. As the demand is satisfied, the hot deck temperature is lowered accordingly, reducing the energy required by the hot deck.

This concept should be used with reset of the cold deck temperature in multi-zone or dual duct systems. Deck temperature becomes responsive to load rather than a schedule based on peak conditions, and the reduced need for mixing saves energy and reduces costs.

Controllers - Old controllers are often the proportional acting type, i.e., dampers or valves which open in proportion to the temperature difference between the set-point and the actual temperature. Such controllers sometimes require higher set-points than necessary to prevent low air discharge temperatures when the outdoor temperature is low. Therefore, the space temperature during occupied periods is often too high, and energy is wasted.

When a proportional integrating controller is installed, a more precise temperature can be maintained year-round, and significant energy savings can be achieved.

Room Thermostat - When heating/cooling is sequenced, there must be a neutral zone (deadband) between the settings so that cooling and heating cannot overlap. For example, room temperatures would be kept at 68°F (20°C) for heating and 75°F (24°C) for cooling. This system is used when both heating and cooling are available at the same time.

Day-Night Thermostat - On radiation and unit ventilation equipment, separate set-points should be provided for day and night operation. Changeover can be accomplished manually or automatically using a time clock or other automatic system.

4.8 Heat-Driven Cooling Systems

An absorption chiller needs high temperature water to operate efficiently. However, during the summer the temperature in most district heating systems is relatively low, generally between 170°F (77°C) and 190°F (88°C). The district heating utility should be consulted regarding the use of hot water for absorption chilling.

It is possible to adapt steam absorption chillers to use hot water, but conversion may not be feasible because the cooling capacity will decrease considerably. It may be more advantageous to install new, more efficient, electric-driven chillers. The economic feasibility of converting steam absorption chillers depend on the relative prices of electricity and the district hot water.

Absorption chillers made specifically for hot water are also available and are in use with 275°F (135°C) water. The maximum water temperature drop in these units is 40°F (22°C), so a large water flow is required. Absorption chillers are also available which are designed to use hot water with a maximum temperature of 180°F (82°C). These units are generally used in conjunction with solar panels, but are compatible with hot water district heating if the primary water temperature during summer is appropriate. Generally, however, these units would not be cost-effective compared to electric chillers unless the price of electricity is very high.

Current research on new heat-driven chilling technologies may increase the efficiency and cost-effectiveness of using district hot water for chilling.

4.9 Humidification and Kitchen Steam Systems

Humidification systems are generally not required in offices and similar buildings where winter temperatures are typically above 32°F (0°C). In colder climates or for other types of occupancy, humidification often cannot be deleted.

Steam cannot be generated by medium temperature hot water during most of the year if the district heating system temperature is reset according to ambient air temperature. Therefore, one of the following solutions must be selected:

- Install small modular electrically-driven steam humidifiers in key areas, or
- Install a new steam generating system.

Limited humidification is often necessary in special areas such as computer rooms and printing equipment rooms. A modular electric steam humidifier can be installed for such applications. These units are small (approximately one gallon or 4 liters) and are fed with cold water.

If extensive humidification is required for certain processes or operations, a separate steam generating system can be installed. An independent steam generator would also be necessary to provide steam for restaurant and cafeteria kitchens having serving tables with vegetable steamers and steam-heated pans and kettles. In these cases, a

central boiler (gas/oil or electric) would generate steam for distribution to the air handling units.

To minimize lime build-up on electric heating elements it is essential that make-up water be pre-heated. This will reduce operation and maintenance costs and extend the life of the electric heating element. Hot water district heating can be used to pre-heat the feedwater to the steam boiler.

4.10 Energy Conservation

4.10.1 Overview

Increased energy efficiency will result from conversion to district hot water. When the conversion design is being developed, additional energy conservation measures should be considered. Older buildings were designed and built before minimum HVAC standards were established via energy codes. These codes specify efficiency standards for HVAC systems and building envelope improvements to provide thermal resistance and minimize air infiltration.

A building's heating and ventilation load should be considered on a seasonal basis rather than for peak conditions only. Energy consumption is often excessive because the distribution system is designed to operate continuously at the maximum capacity required to meet the peak building load, even though this peak occurs for relatively short periods of time. Constant high flow rates and high temperatures result in additional energy consumption sometimes referred to as the "distribution load."

Reducing building load, distribution load, and then improving primary conversion equipment efficiency are most effective when done sequentially, since the latter steps depend on the magnitude of the preceding ones. The potential for reducing the distribution load depends on the operating conditions and characteristics of the distribution system.

It is important to remember that changes implemented for a particular purpose often induce secondary effects that influence energy usage in other parts of the system.

4.10.2 Ventilation

Ventilation is responsible for a large percentage of the heating load. Cold outdoor air introduced for ventilation must be heated to the temperature required for the indoor space. Reducing the amount of fresh air ventilation consistent with occupancy load, as determined by the local code, can result in significant savings. However, the trend is now toward increasing ventilation compared to standards of the late 1970's and early 1980's.

Older buildings without ventilation systems should be reviewed, and ventilation should be added to satisfy exhaust requirements and reduce infiltration.

In large buildings, which require that extensive areas be served by an exhaust system, consideration should be given to using heat recovery equipment to pre-heat incoming air. Life cycle costs should be studied to determine the feasibility of heat recovery in such areas as storage rooms, bathrooms and rooms containing equipment such as computers, air compressors, transformers and other sources of heat.

4.10.3 Building Management Systems

Once the efficiency of the temperature control system has been increased, computerized energy management should be considered. A simple 7-day time clock or a more sophisticated computer system can be installed to monitor equipment, read data, and turn equipment off to maximize energy savings. The type and complexity of the system should be based on building needs. However, regardless of the type of system, air handling fans should be on only when served areas are occupied unless the fans are required in the recirculation mode for heating at night.

In light structured buildings, additional energy savings might be achieved by reducing room temperature during unoccupied hours. This is especially workable for buildings with a heavy reliance on heating in the air handling system. There can be some negative impacts on the district heating utility load profile as a result of night-time cool-down of customer buildings, and the utility should be consulted regarding this approach.

No substantial savings can be realized with temperature set-back in heavy structured buildings because of long cool-down and heat-up periods.

Computerized control systems have the advantage of allowing daily programming of the running times for fans and air handling units. Adjustments can be made based on room temperature, wind speed, etc., and temperatures of air distribution and radiator systems can be matched to achieve the most economical operation.

4.11 Other Considerations

4.11.1 Heating mechanical rooms

Mechanical rooms converted to hot water district heating normally do not need any additional heat other than the heat loss from the installed equipment, except if this equipment is placed in a large room. To assure adequate room temperature, the old combustion air intake and flue gas duct must be thoroughly sealed.

To protect the chimney from moisture and freeze problems, the chimney top should be covered with a hood to keep out rain and snow but still allow for ventilation from the boiler room. The flue duct opening should be equipped with a small adjustable damper.

4.11.2 Asbestos

Existing equipment to be modified or removed during conversion must be checked for the presence of asbestos. If asbestos is found, it must be removed or enclosed according to applicable regulations. In the U.S., the Environmental Protection Agency, the Occupational Health and Safety Administration and some states have regulations on handling and disposal of asbestos contaminated material. In Canada, the Department of Health and Welfare Services Branch should be contacted.

4.11.3 Recapture of Space

District heating equipment requires much less space than boilers and associated equipment and breeching. Consequently, space can often be recaptured for other useful purposes. This should be taken into consideration in the layout of the new installation.

4.11.4 Staffing and Management

The equipment in the building heat exchanger station requires a minimum of staff attention for operation and maintenance. All equipment except the meter, which is usually maintained by the utility, can be monitored by the regular building maintenance personnel. There is no practical need or regulatory requirement for full or partial attendance by licensed operators, as would be the case with boiler operation. Compared to boiler operation, district heating will save labor and maintenance costs, and there is a potential for additional savings in administrative and insurance costs.

A schedule for preventive maintenance of the equipment in the building heat exchanger station should be developed based manufacturers' recommendations. Good records on consumption, temperatures and pressures are helpful tools in a preventive maintenance program.

5. SUMMARY OF SPECIFICATIONS FOR CRITICAL COMPONENTS

5.1 Introduction

Engineering standards for the safety of unfired pressure vessels should follow the current edition and current published revisions and interpretations of the construction codes of the American Society of Mechanical Engineers (ASME), and should conform in every detail to applicable boiler and pressure vessel laws. Each unit should be stamped with the ASME symbol as required by the local governing authority.

Any pressure piping to the heat exchanger or pressure vessel appurtenances, such as valves, meters, and gauges, should be hydrostatically tested to ensure that it can withstand the peak temperature and pressure of the district heating system.

5.2 Heat Exchangers

The building system designer must choose a heat exchanger compatible with the requirements of the district heating system and the needs of the building. The heat exchanger must be selected to provide a low return temperature, according to the requirements of the district heating utility, under all operating conditions encountered throughout the year.

Generally, the maximum primary side design pressure should be 250 psig (1.7 MPa) with a test pressure of 375 psig (2.6 MPa). The secondary side design pressure should meet the building design and test pressure requirements.

A fouling factor based on the mineral content of the water should always be included. To offset the loss in the heater capacity from fouling, the size of heat exchangers for **space heating** should be increased to allow at least a fouling of 0.0003 square foot per °F per Btu per hour (about 0.00006 square meter per °C per hour per Watt), including both the primary and secondary sides. The fouling factor for heat exchangers used for **domestic hot water heating** should be at least 0.002 square foot per °F per Btu per hour (about 0.0004 square meter per °C per hour per Watt). Fouling factors will vary depending on the local water quality and the water temperature rise on the domestic water side.

All gasketed plate heat exchangers should have a gasket material made of Ethylene Propylene Rubber (EPR or EPDM), peroxide cured, with a maximum design temperature of 350°F (177°C).

The gaskets should not have more than a 50% change in hardness or more than a 10% change in volume when exposed to liquid at 212°F (100°C).

Gaskets should be crush-proof at all temperatures within their operational range when tested in accordance with applicable codes.

All brazed plate heat exchangers should be constructed of 316 gauge stainless steel plates brazed together without gaskets, and with stainless steel cover plates and water connections. Shell and spun tube heat exchangers should be made of spirally spun copper tubes. All welded construction shells should be made of steel plates. Pressure drop through the heat exchanger should not exceed 5 psig (34 kPa) at full flow.

For economical selection, heat exchangers should achieve at least 5°F (3°C) differential between primary and secondary return temperatures. The heat exchanger can be

selected for a closer temperature differential, but the unit costs will increase dramatically.

5.3 Strainer

The strainer installed in the primary supply line to the heat exchanger should have a stainless steel mesh screen of 1/24 to 1/16 inch (1.0 to 1.5 mm) maximum. The 1/24 inch size is recommended. The strainer unit should be selected for a low pressure drop. If necessary, a strainer larger than the pipe size can be selected to reduce the pressure drop. The strainer body should be steel, and be flanged or with screwed ends. The unit should be the "Y" type, with malleable iron bushing and blow-down outlet, and should be rated for 250 psig (1.7 MPa),

5.4 Shut-off Valves

Valves on the primary district hot water supply and return piping are generally provided by the customer. Valves can be of the gate, ball, butterfly or plug type; however, use of ball-type valves with Teflon seals and seats is recommended. The valves must be designed for not less than 250 psig (1.7 MPa) working pressure and 250°F (120°C) operating temperature. Low maintenance ball valves with Teflon seals and without packing are preferable.

5.5 Control Systems

The flow control valve should be designed for a maximum pressure of 250 psig (1.7 MPa) and a maximum temperature of 250°F (121°C). The valve should be a single-seated, plug-type with a maximum leakage factor of 0.01% of maximum flow. Minimum rangeability should be 30:1, and the actuator should be equipped for manual as well as automatic operation. Electronic control valves should remain in a fixed position upon power failure. Pneumatic control valves should close upon loss of air pressure.

The relationship between valve travel and heat output should be linear, with an equal percentage characteristic.

Generally, the valve should be designed to withstand a maximum pressure drop of 100 psig (0.7 MPa) without cavitation and excessive noise. Buildings close to the district heating plant in a large district system may have larger pressure requirements.

Safety factors should be avoided in sizing control valves, because over-sized valves will perform poorly.

Controllers should be adjustable for between 1 and 100 seconds response time, and should generally be adjusted for quick response (less than 20 seconds). Controllers should incorporate a proportional plus integral control mode but with integral compensation. All heat exchangers should incorporate outdoor reset control.

Two valves should be piped in parallel if a single valve would exceed 2.5 inches (64 mm) diameter. The units should operate in sequence to satisfy the building heating demand.

5.6 Piping

All piping should be standard weight, black steel pipe. Wall thickness should be according to the schedules listed in American Society of Mechanical Engineers (ASME) Standards B36.10 and B26.19. Fittings should be of the same material, finish, and strength as its associated piping. All piping on the primary side should be welded. Pipe sizes 1.5 inches (38 mm) and smaller may use screwed fittings.

5.7 Insulation

Piping and appurtenances on the primary side should be insulated based on the peak media temperature for the thickness specified in Table 5.1 of ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.) Standard 90-75, and should meet local energy codes.

5.8 Pressure Gauges and Thermometers

Thermometers should have stainless steel immersion wells in the mains, and the wells should have lagging extensions. The unit should be an industrial glass thermometer with a scale graduation of 30°F to 300°F or -1°F to 150 °C, as appropriate, and must have close accuracy and be accessible and easy to read.

Pressure gauges should have 4.5 inch (114 mm) diameter dials with white backgrounds and sharp graduations. Gauges should be graduated in psig, kPa or other units, have a range of one and one-half times the operating range of the system, and be accurate to within 0.25 percent of the maximum dial reading.

A needle valve shut-off at the inlet to each pressure gauge should be provided. The needle valve should have a carbon steel body with stainless steel stem and high temperature reinforced packing.

5.9 Balancing Valves

Balancing valves may be required on the primary side of the heat exchangers and metering equipment. The valves can be of the globe, ball, butterfly or plug type, with memory stops. The valves must be designed to operate at no less than 250 psig (1.7 MPa) working pressure and 250°F (121°C) operating temperature.

5.10 Unions

Pipe unions should be constructed of malleable iron with a ground joint brass to iron seat meeting ANSI standards. They should withstand 300 psig (2.1 MPa) pressure and 550°F (288°C) temperature.

5.11 Safety Valves

Safety relief valves should be designed according to ASME codes. Each valve should be piped separately to the floor drain. Safety valves should be sized to relieve 100% of the heating capacity. Pressure and temperature safety relief valves should be installed on the secondary side only. Valves should be selected taking into consideration the static head of the building where valves are installed.

5.12 Materials Used in Hydronic Piping and Equipment

The primary district heating distribution system has a water treatment program to control corrosion. Each building's closed loop system should also be installed with a complete water treatment program for corrosion control. Dissimilar metals can accelerate the corrosion process. Since the interface between the district hot water heating loop and the building's heating system heat exchangers is distinct, the materials used for the interface can be controlled and limited.

All piping, valves, wells for gauges, thermometers, etc., can be specified to be of the same material quality; for example, black steel piping, carbon steel valves, stainless steel wells, stainless steel or black steel connections on heat exchangers. If it is necessary to have dissimilar metals, such as black steel piping and copper piping on the heat exchanger, the two materials can be insulated from each other so that galvanic coupling can be avoided.

APPENDIX:
CASE HISTORIES

Introduction

The following case histories describe the challenges faced in conversion of five buildings. Table A.1 summarizes key information about each case. All conversion costs have been adjusted to 1988 dollars, and do not include engineering costs. Although the table summarizes costs, a cautionary note is appropriate: these costs should not be used to generalize about conversion of other buildings which may appear at least superficially similar. There are many site-specific factors which affect conversion costs.

CASE HISTORY 1

RAMSEY COUNTY COURTHOUSE/ST. PAUL CITY HALL
ST. PAUL, MINNESOTA

1. Existing Heating System

The Courthouse/City Hall is a 19 story building that had been served by district steam heat. The high pressure steam was reduced to 10 psig (69 kPa) at the building for distribution to room radiators. Two main equipment rooms had supply and return exhaust fans with steam heating coils to provide tempered air for ventilation. Condensate was passed through a shell and tube heat exchanger for pre-heating domestic hot water and was then discharged into the sewer.

In 1978, the building envelope was upgraded with dual-glazed, aluminum-anodized, solar grey windows. Steam consumption subsequently dropped more than 16%, to an average requirement of 15,000 MBtu (4,395 MWh) annually.

2. Conversion

The initial conversion study recommended that: 1) All radiation and heating coils be replaced; 2) New water-to-water heat exchangers, pumps, and associated hydronic equipment be installed; 3) Existing steam supply risers be re-used; and 4) New return piping be installed. The estimated conversion cost, excluding engineering or contingencies, was $595,000 (1981).

Following this study, an evaluation was undertaken, focussing on maximizing re-use of existing equipment.

2.1 Radiation Capacity

Comparison of radiation capacity and heating demands indicated that the installed radiation could provide the needed heat output utilizing hot water, with no supplementary radiation and with a safety factor greater than 15%. This would not have been possible without the previous upgrade of the building envelope.

2.2 Hot Water Circuitry

Existing Piping - Steam piping in the building was circuited into three zones with separate condensate return systems. Air handling units in the basement mechanical room and penthouse were served by a separate steam supply and return piping system.

Modifications - The existing piping was adapted with minimal modification. Some segments of the return lines were replaced to provide adequate capacity for hot water flow, but the circuit remained intact.

The zone one circuit (floors 1-3) serves offices that are open after regular business hours, so this heating system was put on "occupied mode" for most of the year. For energy conservation, other floors which operate on normal 8-hour days were switched to "unoccupied mode" after closing time and on week-ends.

Zones two (floors 4-12) and three (floors 13-19) were converted to two separate hot water heating loops, using existing supply and return pipes. This configuration reduced the static head on existing piping and radiators on the lower floors.

The design temperature drop through the radiators is 10°F to 12°F (6°C to 7°C). Water from the radiators is mixed with the return from the ventilation system to help achieve this temperature drop.

Pipe insulation added during the conversion was projected to result in annual savings of 600 MBtu. Additional savings in pipe heat losses were expected as a result of the reduction in the media temperature. Elimination of the steam traps was projected to save about 230 MBtu annually.

2.3 Ventilation System

Cast iron heating coils in the existing ventilation system were replaced with new hot water coils sized to handle the higher temperature drop in the system. This allowed smaller piping where new piping was needed, and reduced the return temperature.

2.4 Temperature Controls

The radiators in the building had pneumatic control valves and individual thermostats. The control valves were upgraded to meet the pressure, temperature, and capacity requirements of a hot water system. In addition, the bellows were removed from thermostatic steam traps on each radiator so that the body of the trap acts as a balancing valve.

An automatic thermostat night setback system was recommended. In addition to reducing the space temperature, the night setback would reduce the water temperature in the "unoccupied mode" of the system.

These temperature control modifications were estimated to provide annual savings of 3,130 MBtu, with another 1,870 MBtu potentially saved by changing controls so that the building hot water supply temperature is reduced as outside air temperature rises.

2.6 Conversion Costs

In Table A.2 the estimated construction costs are separated into three categories: a) Conversion of the building from steam to hot water; b) Non-routine maintenance costs; and c) Recommended conservation measures.

Costs for conversion to hot water, excluding engineering and contingency, were estimated to be about $428,000 (1981), or 28% less than estimated in the initial study.

Two major conservation steps, night setback and reduced ventilation, were not implemented. Due to budgeting constraints, it was decided that new setback thermostats would be installed as older units fail, rather than 100% replacement during conversion.

3. Results

The building heating pipes, convectors, coils, etc. were air tested and hydrostatically

TABLE A.2

COURTHOUSE / CITY HALL CONVERSION COST ESTIMATE

Items	Cost for Hot Water Conversion	Non-Routine Maintenance Cost	Recommended Conservation Measure	
New Piping, Valves and Unions	65,800	---	---	
Insulation, Piping and Exchangers	20,500	8,500	4,200	
Modifications of Radiators, Convectors, and Unit Heaters	18,500	---	---	
Temp. Control Modifications	122,000	35,000	21,000	
Heat Exchangers and Pumps	43,000	---	---	
Hydronic Accessories	16,480	---	---	
Air Handling Units, Modifications, and New Hot Water Heating Coils	26,500	12,500	---	
Humidifiers (AHU #9 and Computer Room)	7,800	---	---	
Domestic Hot Water Heating Modifications	6,800	1,500	---	
Water and Air Balancing	4,800	---	26,000	
Low Leakage Fresh Air Intake	---	4,900	---	
Electrical Wiring	8,350	---	---	
Demolition	7,000	---	---	
Subtotal Mechanical Costs	$348,030	$62,400	$51,200	
Access Panels	5,000	---	---	
Concrete Pads and Structural Steel	5,000	---	---	
12th Floor Ceiling & Lighting Replacement	42,000	---	---	
Cutting, Patching & General Construction Work	47,000	7,000	---	
Subtotal General Construction Work	79,500	7,000	---	
Total	427,530	69,000	51,200	$547,730
Add: 15% Contingency	64,130	10,350	7,680	82,160
12% Engineering and Inspection Fee	51,304	8,280	6,144	65,728
Total Estimated Construction Cost	542,963	87,630	65,024	$695,617

Note: The costs represent 1981 dollars.

tested to make sure all were leak free and all by-passes from steam main drips were located and isolated. The new hot water system went into operation with very minor adjustments.

Based on actual heating bills, the energy savings exceeded the projected savings of 20%. Temperatures are now even throughout the building, including areas adjacent to the large steam mains, which were previously hot spots.

CASE HISTORY 2

HOTEL JAMESTOWN
JAMESTOWN, NEW YORK

1. Existing Heating System

The Hotel Jamestown is a 10 story apartment building with offices and retail shops on the mezzanine and lobby levels. Periphery heating was primarily accomplished with low pressure steam generated in two gas-fired boilers housed in the basement. The lower floors of the hotel, principally the mezzanine and lobby levels, were served by a central air handling system recently converted to hot water with the introduction of a heat pump.

The steam heating system was a down-feed, two-pipe system composed of 66 steam supply risers and 66 condensate return risers which were located in the outside walls and along interior corridors. One supply main delivered low pressure steam from the basement to the distribution header situated in a crawl space under the roof. Each steam riser served no more than two cast iron radiators on each floor. The return risers run vertically from the roof without lateral excursions until the second floor where many were interconnected before continuing to condensate collection headers in the basement.

The heat pump also relied on the gas-fired steam boilers for proper performance. Producing hot water from the high temperature boiler flue gas, a stack exchanger provided the supplementary heat demanded in the operation of the heat pump system. The heat pump was designed to provide chilled water to the central air handlers in summer and to contribute to the hot water requirements in the cooler seasons. Hot water was supplied to heating coils for maintaining central air temperature and to a heat exchanger for domestic hot water. Winter conditions demanded the firing of the steam boilers and the utilization of the stack exchanger to assure adequate system performance.

2. Conversion

Analysis of fuel consumption records indicated that the peak comfort heating load for the hotel was 2.3 MBtu per hour (675 kW). A peak demand of 1.6 MBtu per hour (470 kW) was estimated for domestic hot water generation. Knowing the heat load requirement and the performance capability of the heating system, a hot water retrofit was accomplished with a primary district water supply of 100 gpm (6.33 liters per second) and a temperature drop from 250°F to 160°F (121°C to 71°C). Estimates for building water system operation were based on a flow of 360 gpm with a temperature rise from 180°F to 190°F (82°C to 88°C) for the periphery system, a flow of 120 gpm (7.57 liters per second) with a temperature rise from 100°F to 120°F (38°C to 49°C) for central air handlers, and a flow of 35 gpm (2.2 liters per second) with a temperature rise from 40°F to 130°F (4°C to 54°C) for domestic hot water.

For the hot water conversion, three plate-type heat exchangers were installed in the basement. The three exchangers, comprised of a periphery unit, central air unit, and domestic hot water heater, are arranged in series on the primary side to maximize temperature drop, providing economical operation in a district heating system. The particular arrangement was determined by the different temperature requirements of each water system.

The heating coils associated with the heat pump were designed to accept lower operating temperatures than the radiators in the periphery system. As a result, the central air unit and domestic hot water exchangers are positioned downstream of the periphery exchanger for efficient utilization of the partially cooled primary supply.

The conversion to hot water district heating was accomplished as follows:

- Installation of 3 plate-type heat exchangers to satisfy the periphery heating system, the central air heating load presently furnished by the heat pump, and the domestic hot water load.

- Installation of circulating pumps, expansion tank, and air removal equipment for the periphery system.

- Recognizing the age of the hotel and the substantial static pressure which is developed in a high-rise dwelling, the existing condensate return lines were not used in the new piping arrangement. Adjacent steam supply risers were isolated, with one serving as a hot water supply line and the other as a return. Each set of risers served two radiators connected in series on each floor.

- Installation of a new piping network in the basement serving as a collection header for return water to assure leak-free operation under substantial static heads. The existing steam main and distribution header situated under the roof was adequately sized and was therefore used for hot water supply to the periphery system.

- Modification of the existing heat pump controls to maximize district heating water utilization during winter months.

- Installation of supply temperature controls based on outdoor temperature.

- Connection of existing water systems for the central air system and domestic hot water to the respective heat exchangers.

- Retrofit of individual radiators, including removal of steam traps and installation of hydronic balancing valves, shutoff valves, and air vents.

- Retirement of the existing condensate return system, steam boilers and condensate handling equipment.

The hotel was retrofitted from steam to hot water in 1985 for a total cost of $115,000 (1985$).

3. Results

The converted system has operated very well, requiring only minor adjustments.

CASE HISTORY 3

GILLETTE INDUSTRIAL FACILITY
ST. PAUL, MINNESOTA

1. Existing Heating System

The facility is used for manufacturing and distributing toiletries and other products, and consists of a 180,000 square foot (16,723 square meter) distribution center and a 660,000 square foot (61,316 square meter) manufacturing center. Prior to conversion to hot water district heating, all heating and process energy needs were supplied with district steam service.

Gillette's annual steam consumption was 32.4 million lbs. of 65 psig (448 kPa) steam, or about 9,500 MWh, annually, of which about 30% was for process heating requirements.

1.1 Space Heating

A 15 psig (103 kPa) two-pipe steam system was supplied through pressure reducing stations connected to the high pressure steam main. The distribution center was heated entirely with suspended steam unit heaters in a single heating circuit. The manufacturing center included three heating circuits, served by air handling units, convectors and unit heaters supplied with steam, and two hot water radiation systems supplied from steam-to-water shell and tube heat exchangers. Ventilation units in the manufacturing center were provided with steam humidifiers.

Separate circuits served product heating and domestic hot water needs. In addition, one of the circuits supplied steam to the tank farm for vaporization of liquified gases and to steam hose connections used for winter thawing of exposed pipes on trucks. Condensate was drained from each terminal heat exchange device through condensate return piping mains to receiver-pump units, and was then wasted to the sewer.

1.2 Process Heating

Product heating is the biggest process heat load. Tank farm vaporization and pipe thawing are relatively small requirements.

Product heating is accomplished primarily in single wall tanks, although a few are double wall (jacketed). The required temperature varies from product to product, but most require 165°F (74°C), and a few require 183°F (84°C). The existing heat exchangers were plate type, steam-to-product or steam-to-water.

1.3 Domestic Hot Water

Domestic hot water is used for cleanup around product mixing areas as well as for restrooms, at an average rate of 39,500 gallons (149,520 liters) per day. The system included a storage type heater with a steam tube mounted directly in the tank. The heater was supplied from the high pressure steam system through a pressure reducing valve.

2. Conversion

An important consideration was that the district heating system proposed to supply water at a variable temperature, from 190°F (88°C) during the summer up to 250°F (121°C) during the coldest part of winter. To achieve a primary return water temperature of 160°F (71°C) or lower during the winter, the conversion included a primary-secondary pumping arrangement at the ventilation coils, series flow of water through unit heaters, and a product water tempering tank.

2.1 Space Heating

All existing steam and condensate mains were reused, except for the condensate lines in the distribution center, which were in poor condition. With the manufacturing center on a separate circuit, the piping was easily modified to permit a series flow of water through the unit heaters to provide a greater temperature drop.

All existing terminal space heating equipment was retained. Considerable effort went into determining the feasibility of circulating hot water in existing steam coils and cooling coils. The steam coils could not be re-used because of their internal design. The pressure drop would have been too high, and the heat transfer too low. However, reuse of existing cooling coils (see Section 4.3.4) was feasible, and this allowed significant savings in conversion costs.

A small number of convectors and fan-coil heating units in the manufacturing center were retained. Although the return water temperatures from these units would be greater than desired, their effect on the system would be negligible, because the volume of water involved is relatively small.

To better assure low return water temperatures from the ventilation unit coils and to reduce coil freezing potential to a minimum, the circuits in the manufacturing center were arranged for secondary pumping circuits with return bypass. This arrangement provides a constant flow of water through the heating coils, and is controlled so that a modulating, three-way bypass valve at the secondary pump is controlled by a space thermostat with return water serving as a high reduced primary supply temperatures.

Since the steam humidifiers were in good condition, electric steam generators supplied with deionized water were installed to connect to the existing humidification systems.

2.2 Process Heating Systems

Conversion of the product heating systems required a design providing flexibility, because these requirements range up to 183°F (84°C), and possibly higher in the future. In the conversion, the high pressure steam piping system was replaced with a new two-pipe direct return hot water circulating system, with branches supplying the various process heat exchangers.

Although the product heating requirements are independent of climatic season, the district heating system supply temperature varies seasonally. With district heating water as low as 190°F (88°C) in the summer, addition of an electric booster would be necessary if in the future new processes were added which required process water temperatures higher than 183°F (84°C).

All existing heat exchangers for product heating were re-used. A new primary heat exchanger was required to transfer heat from the district system to the product heating circuit.

A process water storage tank was included to pre-heat city water. This helps assure that the district water leaving the facility is 160°F (71°C) or less. It also reduces the time required to heat the product mix and reduces condensation on cold water pipes.

Because the heating loads for steam-heated vaporizers and steam hose outlets for thawing were very small and intermittent, the conversion plan recommended that vaporization and thawing be accomplished with electricity.

2.3 Domestic Hot Water

A new primary water-to-water heat exchanger for DHW was installed and the existing hot water storage tank was retained.

2.4 Summary of Conversion

In summary, the conversion plan included the following:

- Provide water-to-water heat exchangers for each space heating circuit.
- Re-use existing steam supply piping in the new hot water recirculating system, re-use the condensate piping where possible, and provide new piping.
- Provide new piping, fittings, valves, pumps, expansion tank and other accessories for hot water recirculation.
- Remove steam coils.
- Modify cooling coil controls to use hot water by installing a smaller heating control valve in parallel with the cooling control valve.
- Modify existing unit heaters for hot water heating and add new units to satisfy heating load.
- Provide water-to-water heating exchangers for process water heating.
- Provide electric steam humidifiers in ventilation system.
- Provide wiring for humidification equipment and pumps.
- Install storage tanks for process water heating.

Cost estimates are shown in Table A.3 in 1980 dollars.

TABLE A.3

GILLETTE FACILITY CONVERSION COST ESTIMATE
(1980$)

Item	
Remove steam coils and modify chilled water coil controls	$ 70,000
Primary Heat Exchangers	55,000
Circulating Pumps	28,000
Water Storage Tank w/ Heat Exchanger	23,000
Space Heat Piping and Insulation	55,000
Product Heat Piping and Insulation	95,000
Humidification System	50,000
Electrical	35,000
Control Systems	25,000
Subtotal	436,000
Engineering Design	50,000
Contingency	69,000
Total Cost	$555,000

3. Results

After two years of operation, the estimated peak demand was adjusted from 16.5 MBtu per hour (4,834 kW) to 15.8 MBtu per hour (4,632 kW).

After conversion, several modifications were made. Additional heat exchangers for process operation were installed to reduce the return water temperature. Controls on the primary side of the heat exchangers were modified to eliminate "hunting" conditions. Demand limiters on the process system's heat exchangers were also added. With these modifications, the system has worked very well.

CASE HISTORY 4

GARFIELD SCHOOL
WILLMAR, MINNESOTA

1. Existing Heating System

The Garfield School in Willmar, Minnesota was built in 1930 and is a 3 story, brick structure. The two-pipe steam heating system was connected to the Willmar district steam system. During the 1970s, various energy conservation measures were implemented, including retrofit of windows with double-pane glass, blocking off selected windows, and installation of control valves in individual rooms.

The existing building system was comprised of 42 radiators and 15 unit ventilators. Some of the appliances had pneumatic control valves with room thermostats, some had on/off valves, and a few had no valve at all. Most of the exposed condensate piping was uninsulated.

2. Conversion

2.1 Cost Estimation

A preliminary budget estimate of $17,000 for secondary side conversion was prepared by a local plumber, based on re-use of all existing equipment but not including any pipe insulation. Building system design consultants were then engaged to prepare the building conversion design, including a schematic flow diagram, working drawings, and technical specifications for bidding. They also calculated a rough cost estimate of $25,000-$30,000 for complete conversion of primary and secondary systems. During the design phase, it was determined that the design heating load was slightly over 1,000 MBtu per hour (300 kW).

2.2 Design Elements

The design elements of the conversion were as follows:

- Steam supply and condensate return piping was re-used as hot water supply and return piping.
- All uninsulated piping was insulated.
- Cast iron radiators, unit ventilators and existing pneumatic control valves were reused with appropriate modifications to adapt to hot water.
- Steam trap internals were removed from each unit's condensate return. The project was bid with complete trap removal and replacement with a new ball valve for flow balancing. This work was deleted at a savings of $5,700.
- New air vents were installed on all appliances.
- On appliances with a bottom supply feed, the pipe was extended to the top to prevent short circuiting.

- The existing domestic hot water storage tank was re-used.
- A circulating loop, with pump, was installed between the secondary side of the domestic water heat exchanger and the existing hot water storage tank.
- A water softener was installed on the domestic water system make-up. Previously, hard water (400 ppm CaCO3) was used for domestic water make-up.
- The hot tap water supply piping was modified with a three-way mixing valve to provide 140°F (60°C) water to the kitchen and 110°F (43°C) water to the rest of the building.

2.3 Conversion Costs

The complete installed cost of the building conversion, excluding engineering, was $20,216, or approximately $67 per kW, broken down as shown in Table A.4.

TABLE A.4

GARFIELD SCHOOL CONVERSION COSTS
(1988 $)

Primary Side		
Installation		$ 2,600
Materials		
Heat exchanger (heating)	543	
Heat exchanger (DHW)	547	
Control valve systems (heating and DHW)	1,646	
Metering	1,080	
Pipe insulation	200	
Total		4,016
Total Primary Side		6,616
Secondary Side		
Original bid		19,300
Minus savings by changing to removal of trap internals instead of complete trap removal		5,700
Total Secondary Side		13,600
Total Cost		$20,216

3. Results

The system was started up in August 1988. As of February 1989, the system temperature difference has averaged 41°F (23°C) on the primary side. Although this does not meet the Willmar Municipal Utilities target of 60°F (33°C) design temperature difference, the conversion was very cost-effective for the customer and has provided otherwise excellent technical performance.

A definitive analysis of energy use and savings achieved is premature at this time. However, the limited data indicates significant energy savings from the conversion. Energy consumption from the hot water system as of February 1989 shows a 21% savings compared to 1987-88, and an 18% savings compared to 1986-87.

CASE STUDY 5

CHARLOTTETOWN HOTEL
CHARLOTTETOWN, PRINCE EDWARD ISLAND

1. Existing Heating System

Oil-fired boilers located in the basement of the hotel generated low pressure steam at a maximum of 15 psig (103 kPa). Space heating was accomplished by three different methods. The basement and the first floor including a mezzanine level were heated directly by steam with unit heaters and cast iron radiators. The three bedroom levels were heated by hot water from a steam-to-water heat exchanger. Each bedroom unit has an individually controlled air heating coil. The top floor, which contains office space, was heated by electric baseboard heating elements.

Considerable amounts of energy are required for kitchen and laundry facilities and the bedroom units. Domestic hot water for the bedroom units and the kitchen was provided by two steam heated 600 gallon storage tanks. The kitchen also required steam for steam kettles and a dishwasher booster heater. The laundry was served by a separate steam heated storage tank located in the laundry room itself.

Recirculated pool water was heated by a small steam-to-water heat exchanger also located in the laundry room.

The net energy consumption of the hotel had not been monitored prior to connection to the district heating system. The hotel did, however, monitor fuel oil deliveries, which were used to obtain a reasonable estimate of the energy consumption. Annual energy consumption was estimated to be 6,990 MBtu (2,048 MWH) and the peak demand was calculated to be 3.1 MBtu per hour (910 kW) using a seasonal boiler efficiency of 66% and an estimated utilization time of 2,250 hours.

It was also estimated that, of the total energy derived from fuel oil, hot water space heating accounted for 55%, domestic hot water 12% and steam space heating 33%. Conversion of the top floor, which was electrically heated, would add approximately 100 MWh of annual energy consumption.

2. Conversions

2.1 Initial Conversions

The initial conversions included all heating requirements already being met with hot water, including domestic hot water, pool heating and 55% of the building's space heating.

Building Space Heating - The existing heat exchangers did not meet the temperature or pressure requirements of the district heating system, so a new water-to-water heat exchanger, sized to provide the peak demand after complete conversion, was specified. A standard indoor-outdoor control was selected, with provisions for maximum limitation, set back control curve and room temperature set point control with automatic control curve adjustment.

Domestic Hot Water - Domestic hot water (DHW) temperature and flow requirements were of primary concern during the design stage. The recommended heat exchanger installation was an instantaneous two stage coupling for generating DHW at 130°F (54°C). This temperature would be satisfactory for the requirements in the bedroom units but might necessitate some boosting for the laundry and kitchen requirements. With modern low temperature wash chemicals, a steady supply of DHW at 130°F (54°C) has proven quite satisfactory. Connection of the laundry required the installation of a separate hot water line from the basement mechanical room to the laundry.

Kitchen Facilities - The kitchen requires moderate amounts of steam for steam kettles and a dishwasher. The dishwasher has an internal tank and steam coil to maintain a constant supply temperature of 140°F (60°C) to the washer and a two stage steam coil booster to achieve 160°F (71°C) and 180°F (82°C) for washing and rinsing respectively.

Several options were considered for the dishwasher, including converting the internals of the washer to an electric booster; installing separate electric or propane water heaters; and installing a new low temperature dishwasher.

However, the steam kettles would still require approximately 70 lb. per hour of steam. Therefore, the most cost-effective option was to install a small steam boiler for both the dishwasher and steam kettles. Because the hotel would initially require some steam for space heating as well as for the kitchen, the boiler was sized to provide the kitchen and space heat requirements in the spring and fall. Sizing this boiler for spring and fall would limit its size, and the existing boilers could supply steam for the remainder of the season while still running at an acceptable load factor. The recommended boiler size was 0.51 MBtu per hour (150 kW).

Swimming Pool Heater - Steam was being used to heat the pool water to approximately 80°F (27°C). One option considered was to replace the existing heat exchanger with a water-to-water unit and use the building heating water to heat the pool water. This would require elevated temperatures on the secondary system on a year round basis. This option was rejected because it would raise the primary return temperature. Instead, a heat exchanger in the primary loop was installed and pool water was circulated on the secondary side.

2.2 Remaining Conversions

Existing Steam System - After operating on the district heating system for one heating season, the remainder of the building was converted to hot water. Very little of the existing steam piping and equipment was usable. The existing piping and fan coil units on the mezzanine level were leaking and required continuous maintenance. Pipe routing was not appropriate for hot water distribution. The existing piping was abandoned and a new hot water perimeter baseboard system was installed.

The steam unit heaters in the pool and the existing cast iron radiators in the first floor office area were large enough to be used with hot water, although new piping was required.

Hot Water Piping - New hot water piping was installed in a reverse return configuration, with the main 3 inch (76 mm) heating loop installed around the basement ceiling perimeter. Individual sections in the basement, first floor and mezzanine levels were fed

separately from the main loop in the basement. It was recommended that all zones b individually controlled with zone valves and that no by-passes be installed in order t keep return temperatures to the district heating system low.

Electrical Heating - Conversion of the top electrically heated floor required extension o the main supply and return piping. All electric baseboard was replaced with hot wate baseboard radiation around the perimeter wall. Distribution piping was installed in a reverse return configuration to provide a self balancing system.

2.3 Conversion Costs

The original feasibility study cost estimates, which were based on other representative sites, are listed in Table A.5, Column 1. Actual costs are shown in Column 2.

Table A.5

CHARLOTTETOWN HOTEL CONVERSION COSTS

Initial Conversion	(1) Estimated costs (1985 dollars)		(2) Actual costs (1986 dollars)
Heat Exchangers	5,000		14,680
Installation	9,831		
Piping Materials	13,000		
Steam Boiler	*	==>>	42,758[1]
Controls	1,900		
Heat Meter	800		
Total	$30,531		$57,438[2]
Additional Conversions			
Material	*		25,000
Labor	*		35,000
Total	*		$60,000

* Not included in the original study.

1 This cost represents the total cost of the installation including: labor and materials for heat exchanger station installation as well as the additional steam boiler.

2 Increased costs above the original estimates were due to an increased number of heat exchangers at higher costs, the addition of a steam boiler, and additional piping in the building to complete a connection. The original study did not allow for a two stage coupling and a pool heater.

3. Results

The converted system has operated successfully with some adjustments. Problems were encountered with the newly installed pool heater. Flow requirements for proper water filtering were underestimated and the resulting pressure drops through the extra piping and new heat exchanger were significantly higher than expected. Considerable time was spent to achieve the proper flow and temperature balance. The heat injection circuit piping should be short to avoid excessive pressure drops and the heat exchanger should be sized primarily on pressure drop requirements.

High domestic hot water temperatures have been reported on very cold days and during periods of low demand (at night). This is a result of the nature of the two stage coupling and the fact that return temperatures from the heating heat exchanger can be above 176°F (80°C) during cold periods. This, however, is a manageable issue, and the two stage coupling does offer the potential for very low primary return temperatures.

None of the control strategies other than the indoor-outdoor supply water reset were implemented due to the unpredictability of the hotel's occupancy and special functions.

After conversion of the steam heated floors, problems occurred in heating the dining room, which is located directly above the mechanical room. When the boilers were shut down, the dining room lost a major source of heat. Insulation had to be added to overcome the loss of the heat previously added by the boiler. Care must be taken in estimating heat loads in situations such as these.

The conversion has resulted in significant energy and cost savings. Energy use has decreased 8-10%, and maintenance costs have been reduced by about $3,000 annually. In addition, the hotel plans to convert the boiler room into a health club and squash courts.

GLOSSARY

Absorption chiller - A refrigerating machine using heat energy to generate chilled water.

Air heater - A set of heat transfer coils or sections used to heat air that is drawn or forced through it by a fan. A unit heater.

Air handling system - Equipment which provides for the distribution of tempered air.

Balancing valve - A valve installed to adjust the distribution of water to a specific location.

Baseboard radiator - A heating device located at or replacing a room baseboard.

Blast coil - A heat transfer surface, most frequently of an extended surface arrangement, over which air is blown to be heated or cooled.

Blowdown - The discharge of water from a boiler or cooling tower that contains a high proportion of dissolved solids.

Booster coil - Coil in an air recirculation system for tempering recirculated air. Also called a reheat coil.

Closed loop or closed cycle - A cycle in which the fluid is recycled without introduction of new fluid.

Convector - A radiation unit designed to heat room air primarily by convection.

Direct connection - Connection of building heating equipment (heating coils, radiators, etc.) directly to the primary district heating distribution system without first transferring the heat to a separate secondary system through a heat exchanger.

Direct return heating system - A two-pipe system that returns the heating medium from the terminal exchange to the heat source (district heat exchanger or boiler).

Double wall heat exchanger - A heat exchanger in which the two fluids are separated by two walls with another fluid or air space in between.

Dual duct system - A system that produces conditioned air at two temperatures and humidity levels. The air is then supplied through two independent duct systems to the points of use where mixing occurs.

Fan coil unit - A fan and heat exchanger for heating and/or cooling, assembled within a common casing.

Fin-tube radiator - Heat transfer tubes or pipes with an extended surface of fins, disks or ribs.

Heating coil - A heating element made of pipe or tube that may or may not be finned or formed into helical or serpentine shape.

Heat exchanger - Device designed to transfer heat between two physically separated fluids. In district heating systems, heat exchangers transfer heat from the primary hot water supply to water on the secondary side, which is then circulated within the customer building.

Induction unit - A jet action device that injects treated air to entrain recirculated air through a heat exchanger.

One-pipe system - A steam piping system in which the steam withdrawn from the supply main passes into a heating unit, with condensate return through the same pipe.

Plate heat exchanger - A heat exchanger with fixed plates separating the fluids on the primary and secondary sides.

Pre-heat exchanger - A heat exchanger which heats air or water ahead of other processes.

Primary system - Hot water distribution network from the district heating utility, including the primary hot water supply to the heat exchangers in the customer buildings served by district heating, and the primary hot water return from buildings.

Radiant floor heat - A system for heating in which heat radiates to the heated space from heating pipes in the floor.

Reheat coil - Coil in air handling systems for increasing the temperature of air after a cooling cycle. Also called a booster coil.

Recirculated air - Air taken from a space and returned to that space, usually after being passed through a conditioning system.

Return air - Air extracted from the conditioned space and totally or partly returned to the air conditioning system.

Rooftop unit - Equipment mounted on the roof in which conditioned air is discharged directly in the room below or through ductwork.

Secondary system - The hot water supply and return in the customer's building, which circulates through the heat exchanger to obtain heat from the primary system and supplies heat to terminal equipment and air handlers.

Shell and tube heat exchanger - A nest of tubes or pipes, or a coil of tube or pipe, contained in a shell or container. The pipe (or pipes) carries one fluid, and the shell has an inlet and outlet for flow of another fluid.

Steam trap - A device that drains condensate out of steam pipes without allowing any steam loss.

Terminal equipment - Equipment through which heat is finally delivered to the building space, e.g., coils, radiators, unit heaters etc.

Three-way control valve - A valve having either a single inlet and two outlets (diverting valve) or two inlets and a single outlet (mixing valve).

Two-pipe system - A piping system with a supply pipe into a heating or cooling unit and a separate return pipe going back to form a closed loop system.

Unit heater - A set of heat transfer coils or sections used to heat air that is drawn or forced through it by a fan. Also called an air heater.

Ventilation unit - A fan coil unit for applications in which outdoor and return air mixing satisfies tempering requirements and ventilation needs.

TABLE A.1
SUMMARY OF CASE HISTORIES

Building	*Location*	*Peak Demand*		*Conversion Cost (1988$)*	*Conversion Cost Per*		*Heating System Types*	*Key Aspects of Conversion*
		MBtu/hr.	*kW*		*MBtu/hr*	*Kw*		
1. Courthouse/ City Hall	St. Paul, Minnesota, U.S.A.	8.8	2,585	$556,400	$ 63,227	$215	- Steam radiators - Steam coils in air handling system	a. Ability to re-use existing convectors due to prior conservation measures. b. Re-used existing piping. c. Energy savings from conversion.
2. Hotel Jamestown	Jamestown, New York, U.S.A.	3.9	1,145	$126,436	$ 32,419	$110	- Steam radiators - Lower floors served by hot water from heat pump in air handling system	a. Used multiple subcircuits to maximize temperature differential. b. Re-used supply piping but not condensate piping.
3. Gillette Industrial Facility	St. Paul, Minnesota, U.S.A.	15.8	4,632	$625,956	$ 39,617	$135	- Steam unit heaters - Steam convectors - Steam ventilation units - Hot water radiators - Various process heating and misc. needs met with steam.	a. Met process heat needs while meeting district system temperature differential requirements throughout the year. b. Used cooling coils for heating. c. Electric units used to replace steam for miscellaneous uses, including vaporization, thawing, and humidification.
4. Garfield School	Willmar, Minnesota, U.S.A.	1.0	300	$ 20,216	$ 20,216	$ 67	- Steam radiators - Steam unit ventilators	a. Re-used supply and condensate piping b. Re-used cast iron radiators and unit ventilators. c. Steam trap internals were removed instead of complete trap removal and replacement with a new ball valve for flow balancing.
5. Charlottetown Hotel	Charlottetown, Prince Edward Island, Canada	3.1	910	$ 64,763	$ 20,891	$ 71	- Steam cast iron radiators - Steam unit heaters - Hot water air heating coils - Electric baseboard	a. Successfully solved problems in heating swimming pool b. Small steam boiler used to meet kitchen and laundry steam needs. c. Due to pipe condition and routing, little existing pipe was re-used.

IEA District Heating

GUIDELINES FOR CONVERTING BUILDING HEATING SYSTEMS FOR HOT WATER DISTRICT HEATING

Published by
Netherlands Agency for Energy and the Environment

Mailing address: P.O. Box 17, 6130 AA Sittard, the Netherlands
Street address: Swentiboldstraat 21, Sittard
Telephone: +31 4490 95295
Telex: 36456
Telefax: +31 4490 28260

1990 R8
ISBN 90-72130-12-X

Price:
$ 100 for member countries
$ 300 for non-member countries